

A Conversation with Kanti Mardia

Nitis Mukhopadhyay

Abstract. Kantilal Vardichand Mardia was born on April 3, 1935, in Sirohi, Rajasthan, India. He earned his B.Sc. degree in mathematics from Ismail Yusuf College–University of Bombay, in 1955, M.Sc. degrees in statistics and in pure mathematics from University of Bombay in 1957 and University of Poona in 1961, respectively, and Ph.D. degrees in statistics from the University of Rajasthan and the University of Newcastle, respectively, in 1965 and 1967. For significant contributions in statistics, he was awarded a D.Sc. degree from the University of Newcastle in 1973. He started his career as an Assistant Lecturer in the Institute of Science, Bombay and went to Newcastle as a Commonwealth Scholar. After receiving the Ph.D. degree from Newcastle, he joined the University of Hull as a lecturer in statistics in 1967, later becoming a reader in statistics in 1971. He was appointed a Chair Professor in Applied Statistics at the University of Leeds in 1973 and was the Head of the Department of Statistics during 1976–1993, and again from 1997 to the present. Professor Mardia has made pioneering contributions in many areas of statistics including multivariate analysis, directional data analysis, shape analysis, and spatial statistics. He has been credited for path-breaking contributions in geostatistics, imaging, machine vision, tracking, and spatio-temporal modeling, to name a few. He was instrumental in the founding of the Center of Medical Imaging Research in Leeds and he holds the position of a joint director of this internationally eminent center. He has pushed hard in creating exchange programs between Leeds and other scholarly centers such as the University of Granada, Spain, and the Indian Statistical Institute, Calcutta. He has written several scholarly books and edited conference proceedings and other special volumes. But perhaps he is best known for his books: *Multivariate Analysis* (coauthored with John Kent and John Bibby, 1979, Academic Press), *Statistics of Directional Data* (second edition with Peter Jupp, 1999, Wiley) and *Statistical Shape Analysis* (coauthored with Ian Dryden, 1998, Wiley). The conferences and workshops he has been organizing in Leeds for a number of years have had significant impacts on statistics and its interface with IT (information technology). He is dynamic and his sense of humor is unmistakable. He is a world traveler. Among other places, he has visited Princeton University, the University of Michigan, Harvard University, the University of Granada, Penn State and the University of Connecticut. He has given keynote addresses and invited lectures in international conferences on numerous occasions. He has been on the editorial board of statistical, as

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well as image related, journals including the *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *Journal of Environmental and Ecological Statistics*, *Journal of Statistical Planning and Inference* and *Journal of Applied Statistics*. He has been elected a Fellow of the American Statistical Association, a Fellow of the Institute of Mathematical Statistics, and a Fellow of the American Dermatoglyphic Association. He is also an elected member of the International Statistical Institute and a Senior Member of IEEE. Professor Mardia retired on September 30, 2000 to take a full-time post as Senior Research Professor at Leeds—a new position especially created for him.

In April, 1999, Professor Kanti V. Mardia was invited to the University of Connecticut as a short-term guest professor for four weeks. This conversation began on Monday, April 19, 1999 in Nitis Mukhopadhyay's office in the Department of Statistics, University of Connecticut, Storrs.

FAMILY BACKGROUND

Mukhopadhyay: Kanti, shall we start at the origin, so to speak? Where were you born?

Mardia: I was born in Sirohi on April 3, 1935. Sirohi, about ten thousand square miles in area, was the capital of the Sirohi State in Rajasthan, before India's independence. Subsequently, the Sirohi State became the Sirohi district. Sirohi is situated about four hundred miles east of Bombay. One of the greatest wonders near my place of birth has been the hill station, Mount Abu. It has one of the finest Jain temples, Delwara, with gorgeous Indian architecture from the eleventh century. The exquisite details are all meticulously hand-curved on marble, without parallels anywhere else in India. Those shapes and formations on the ceiling and columns with intricate details influenced me even when I was small child. Much later in my life, some of those incredible shapes made deeper and more tangible impacts on my research career.

Mukhopadhyay: Please tell me about your parents.

Mardia: I come from a business family. My father's and mother's names are, respectively, Vardichand and Sanghari. My father inherited the business of money-lending from my grandfather and he had a pawnbroker's shop in Bombay. My grandfather started with practically nothing but through his business acumen acquired a large fortune.

But, my father had to live through some tragedies. He lost his father, two brothers and their families in the span of one year in an epidemic. Due to the spread of some severe unknown disease in that particular area,



FIG. 1. *Kanti Mardia on his uncle's lap, Bombay, 1940.*



FIG. 2. *Ceiling from Jain Temple at Mount Abu (Rajasthan), Sirohi District. Original in white marble with tendrils circling in a fractal form, 1031 AD.*

many in his family perished. My father, about sixteen, was practically the lone survivor in his family.

Mukhopadhyay: How did this episode affect your father and the family?

Mardia: It had a devastating effect. My father started taking life very philosophically and decided to take everything easy. His whole perspective of life changed. He passed on the family businesses to my uncles. One uncle was a compulsive gambler who piled up huge debts. Eventually, many of the family businesses and other assets (e.g., several buildings and movie theaters in and around Bombay) were lost as loan payments on those debts. By the time I turned ten, our family had already slipped down from a very rich status and joined the upper middle class.

Mukhopadhyay: What about your mother's side of the family?

Mardia: My maternal grandfather was a lawyer and writer. He was an original thinker. He wrote a number of novels. Any writing skills I may have, I probably inherited from him.

Mukhopadhyay: How about your brothers and sisters?

Mardia: I have four brothers and one sister. It is a large family. I am the one in the middle, a kind of the "median," a robust estimator. (Laughs.)

I became the first college graduate in the family. My brother Mangesh Kumarji looked after the family-run businesses. He earned real money to support the family while I had to study for my degrees! (Laughs.)

Mukhopadhyay: Was any of your siblings mathematically oriented?

Mardia: My younger brother Babu followed my footsteps and got a masters degree in pure mathematics. He is an Associate professor of Mathematics in Rajasthan University, Udaipur, India. During my childhood and school days, we lived in Sirohi as well as in Bombay, a major city center for all the businesses. We had to shuttle between these two places.

SCHOOL DAYS

Mukhopadhyay: Where and how did your schooling begin?

Mardia: In kindergarten, we learned numbers and even simple fractions. For example, at the age of four or five, we learned the concept of what is one-half of ten or one-quarter of eight! We had to memorize such multiplication tables and the teachers were very strict. We also had to learn to speak and write in Hindi, but this had to be mastered with the Rajasthani script

and dialect, even though those styles were practically dead by then. It did feel like I was mastering a foreign language. This was on top of learning English.

Mukhopadhyay: Did you happen to have some inspiring teachers?

Mardia: In my time, there was only one high school in Sirohi, which I had to attend. Neither the teachers nor the curriculum had any flexibility and I did not like most of the subjects very much, except for mathematics. In the lower grades, we had a mathematics teacher who hailed from Ajmer, another part of Rajasthan, and he had an interesting habit. He used to assign challenging mathematical puzzles to the class and gave small prizes to whoever could solve the puzzles first. I was pretty good in solving such mathematical puzzles and won many prizes along the way. This math teacher had a big influence on me. I also enjoyed plane Euclidean geometry very much. I went through these constructions and proofs of theorems based on axioms. However, I have to confess that I preferred algebraic derivations and proofs with equations to the geometry-based arguments. (Laughs.)

Mukhopadhyay: (Laughs) Kanti, in quiet moments, sometimes you probably think what an irony of life that was!

Mardia: (Laughs) Nitis, you are right. Later in life, "geometry" became my mantra. What an irony indeed! I was not very interested nor considered particularly bright by others in nonmathematical subjects. I loved mathematics and sometimes I got into trouble because of this. Often I would come up with answers too quickly even for tricky problems. In higher grades, I became proficient in the factorization of quadratic equations, but some teachers did not appreciate that very much. Some teachers misjudged me, thinking that I was trying to show off or I was probably too clever. I was just being my enthusiastic self.

When I was about fourteen, I had to choose between the science stream or the arts stream. I did not care much about laboratory experiments and hence avoided pursuing the science stream. Instead I wanted to learn Sanskrit in the arts stream. So, I followed the arts stream.

Mukhopadhyay: Did you take the matriculation examinations from the same school?

Mardia: Yes, this was the only school in our area. I passed the matriculation examinations in 1951 and prepared for my transition to a college. But going to a college meant that I would have to migrate to another area and stay away from home, sweet home.

COLLEGE LIFE

Mukhopadhyay: Which college did you attend?

Mardia: The Jaswant College in Jodhpur (Rajasthan) was the closest to where we lived. I enrolled there for the two-year interscience degree. For someone like me who never took any science courses in school, there were not many choices of such interscience programs available in other universities or colleges. Jaswant College was about one hundred fifty miles from home. For the first time I stayed away from home. The hostel life was quite interesting.

I studied physics, chemistry and mathematics. I was terrible in the lab experiments (which we called the “practicals”). I dreaded the chemistry experiments with all those tubes and chemicals! I hardly had any clues! However, I used to enjoy the theories of physics, organic and inorganic chemistry, and the equations. But, when it came to lab experiments, I froze instantly. (Laughs.)

Mukhopadhyay: I can relate to this. I was quite weak in those chemistry practicals too. (Laughs) I assume that you fell in love with mathematics more.

Mardia: I really enjoyed learning the formative mathematics, for example, calculus, trigonometry, algebra, combinatorics. This was the first time I encountered the beauty of calculus. In the final examinations, I did well and came almost at the top of the graduating class. I got the I.Sc. degree in 1953 from Jaswant College which was affiliated with Rajasthan University.

Mukhopadhyay: What was special about those mathematics courses?

Mardia: The concepts of limits and derivatives were fascinating. I loved direct approaches through first principles rather than mechanically obtaining results. The principles and results from trigonometry were attractive. There was a book by S. Loney on this subject and I remember painstakingly solving every exercise from that book by myself. I really started enjoying the theoretical foundations and took studies very seriously. I surprised myself! (Laughs.)

ISMAIL YUSUF COLLEGE—UNIVERSITY OF BOMBAY

Mukhopadhyay: I am sure that this helped in building your confidence. At this point, you were probably saying, “Look out University of Bombay, here I come!”

Mardia: Nitis, you are correct. Earlier I was not qualified to attend the prestigious University of Bombay for the interscience degree. But now the door was



FIG. 3. *Kanti Mardia in Jaswant College, Jodhpur, 1952.*

open for me. By this time, most of our family had settled in and around Bombay, State of Maharashtra (earlier called the Bombay State). I was looking forward to attending the University of Bombay for the B.Sc. degree and at the same time I would stay close to the family. It was a great opportunity.

Mukhopadhyay: In the University of Bombay, what was your major?

Mardia: In 1953, I entered Ismail Yusuf College, a relatively small but prestigious college in a beautiful suburb, affiliated with the University of Bombay. I took mathematics as my major and physics as the subsidiary subject. I finished the physics requirement in the first year itself and thus in the final year I could concentrate only on mathematics. In physics, again there were those dreaded practical lab experiments, but I took care of them in my first year. What a relief it was for me! (Laughs.)

I found that my fellow students and others did not converse in Hindi. They all spoke in English. It felt like I was visiting another country altogether! I was used to writing in English, but I did not regularly speak in English. I slowly adapted, but first I had to get over a severe cultural shock.

It was an opportune time, though. The college had just started its math degree program. Professor Phadke, the Head of the Department of Mathematics, was an excellent teacher. Every student was required to have two elective papers, either in astronomy or statistics. I wanted to pursue astronomy, but the mathematics department had recently hired a young faculty member, Mr. Mehta, who graduated from the university with statistics. So I did not really have a choice. I ended up with both the elective papers in statistics—one

paper on probability and another on inference and data analysis. It was a blessing in disguise!

Mukhopadhyay: In your course work, were you taught mostly from standard books or notes?

Mardia: Most advanced courses were taught by Professor Phadke. He was very smart and an excellent teacher. He came to each class fully prepared. He wrote clearly on the chalk board, taught interactively, and explained everything without looking at any notes or books. He was very impressive.

I was his favorite pupil in the class. After asking questions, he used to look at me and he fully expected me to come up with an answer. Sometimes I might not have been able to give answers as quickly as he expected and then I could sense that he was getting a little frustrated. One day he asked, "Where do two vertical planes intersect?" This question confused me. I could not feel the geometry at all. I was giving him two equations in three variables and then algebraically trying to find the common points. Naturally, this was taking some time. But, at that point the professor became very impatient because I was not seeing the answer that was obvious to him. He started explaining, "Look at this wall and that wall in the classroom. Where do they intersect?" As soon as he started drawing my attention to these vertical walls, it dawned on me that the answer was truly obvious. He wanted to hear some simple answer and I was throwing at him a couple of equations instead! (Laughs.)

I realize now why my teacher was getting restless. But I must tell you that Professor Phadke never meant any harm. He was refreshing and always challenging with very high expectations. I remain grateful to him forever.

Mukhopadhyay: Would you add anything about your other statistics professor, Mr. Mehta?

Mardia: Mr. Mehta was starting his own teaching career. He was young and very intelligent, and he focussed on doing everything right. He gave us excellent lecture notes. He did not have much experience and so he probably shied away from challenging us. He was very thorough and was available for extra help and guidance. We became very friendly. When I visit India, I make an attempt to go and see him.

UNIVERSITY OF BOMBAY

Mukhopadhyay: What influenced you to switch from mathematics to statistics?

Mardia: The top students normally opted for the engineering or the medical school. My parents wanted me to pursue that line too. I actually got admission

to the engineering school of the prestigious Victoria Jubilee Technical Institute, Bombay. Someone hinted that if I went for a masters degree in statistics, I could become a fellow of the Ismail Yosuf College, a position which carried much honor and it also paid a stipend. In 1955, the subject of statistics was growing and so one could be very innovative. I heard from others that this discipline would offer a challenging future for bright people. The opportunities were plentiful as I understood.

I asked Mr. Mehta for advice and he said that "statistics" was the way to go. Each bit and piece of information convinced me that this route was more appealing than becoming an engineer or a doctor. My family had to be convinced that pursuing a two-year masters degree program in statistics would be more useful in the long run, and eventually they agreed.

The Department of Statistics at the University of Bombay was very highly regarded and it was quite special because this department was allowed to award its own masters degrees. Unlike in pure mathematics, there was tough competition to get admitted in statistics at the University of Bombay. I did not understand all the ramifications of what I was getting into. But because it was so hard to enter a program like that, I took it as a challenge and applied for admission during the first part of 1955.

Mukhopadhyay: What did you experience when you entered the masters program in statistics?

Mardia: Professor M. C. Chakrabarti, a great expert in the combinatorics and constructions of designs, was the Head of the Department of Statistics. I recall that he taught us probability. He was very methodical and an excellent teacher. Multivariate analysis and statistical inference were taught, respectively, by Professors A. M. Kshirsagar and Kamal Chanda (both of whom have been living in the United States for many years now). Professor K. S. Rao, an economist, was also on the faculty. All the professors were excellent. I am still in touch with Professor Kshirsagar.

There were very few textbooks and frequently we had to learn the materials directly from the journals. We often referred to *Biometrika*. In addition to the class notes and journal articles, I remember studying page-by-page from H. Cramér's *Mathematical Methods of Statistics* (1946) and C. R. Rao's *Advanced Statistical Methods in Biometric Research* (1952). Because of Professor Chakrabarti's eminence, we were taught a variety of materials on design of experiments for which we essentially relied upon W. G. Cochran and G. M. Cox's *Experimental Designs* (1950) and

O. Kempthorne's *The Design and Analysis of Experiments* (1952). I was young and I came here with an impression that I was very good. But, once I landed in this department, it took me no time at all to realize that there were other intelligent people too! (Laughter.)

On a serious note, I immediately felt the challenging aspect of the program. The very high standard of teaching and research led to high expectations of the best and brightest students in the department. One had to be real sharp to survive such a level of tremendous pressure.

Mukhopadhyay: Who were some of your fellow students at the University?

Mardia: Babubhai Shah was my classmate. He was very bright. He has been at the Research Triangle Institute in Research Triangle Park at Raleigh, North Carolina. Jon N. K. Rao at Carleton University was one year senior to me. Jon was very sharp and popular. When we got stuck in a problem, sometimes we would ask him for advice. I remember that one time I was working on the distribution of the range in a random sample from some distribution and Jon Rao instantly came up with important suggestions on possible plans of attack. C. G. Khatri was two years ahead of me and unfortunately he is no longer alive. Kirti Shah at the University of Waterloo was one year junior to me. G. S. Maddala was my contemporary too. He was very clever and very good with the statistics practicals. I have lost touch with most of these friends. I have been able to keep in touch only with Babubhai and Jon Rao through all these years.

Mukhopadhyay: In the M.Sc. curriculum, which areas in statistics attracted you the most?

Mardia: Multivariate analysis and matrix algebra were definitely my two favorite subjects. The derivations were mostly algebraic, rather than geometric. I will say that statistical inference was the next in line. Wishart's (1928) original derivation of the Wishart Distribution fascinated me. At this stage, I was not exposed to the geometric approaches in statistics. I relied heavily upon algebraic and analytical derivations rather than the more intuitive geometric validations. Even now I do not have full faith in purely geometric "proofs."

Mukhopadhyay: Do you recall any aspect of the masters program that you did not enjoy much?

Mardia: I did not enjoy statistical calculations with the Facit machines. One had to turn the handle in one direction for addition/multiplication but in a opposite direction for subtraction/division. We depended on this machine for evaluating the square root of a number

or for inverting a 4×4 matrix, and for that matter in all statistical calculations. During an exam, the whole room would be so noisy that it sounded like a factory. My usual problem was that if I repeated the steps to check any calculations, I very rarely got the same answer again! That was very frustrating. There was no way to be sure that the Facit machine's handle was turned in the right direction and the right number of times, particularly during an exam! I still remember that. (Laughs.)

Mukhopadhyay: Kanti, please excuse me. I cannot resist the urge to say this. It seems that you could not shake off the "ghosts" of the "practicals in physics and chemistry" that easily. You thought that you did, but the "ghosts" reappeared to haunt you with the disguise of Facit machines. (Laughs.)

Mardia: (Laughs.) You are right. I just could not get away from the so called "practicals," even in statistics! I always struggled with those Facit machines. You can only guess the relief and mental peace I derive from the personal computers I have.

Mukhopadhyay: Would you say that in the mid-to late 1950s, the statistical research program at the University of Bombay was in the forefront?

Mardia: Yes, the statistical research program at the University of Bombay was in the forefront. Professor M. C. Chakrabarti was internationally known and he was the star of the group. In 1956, there was a meeting of the International Statistical Institute in Calcutta and many notable personalities participated. On their way to or from Calcutta, some of the delegates came to Bombay to visit the Department of Statistics. I remember that Professor S. N. Roy came and gave a lecture on multivariate analysis. Professor Roy was wearing a typical Bengali attire, dhoti and punjabi. Everybody had so much regard for him that during his talk nobody said anything. Everyone listened intensely to whatever Professor Roy had to say. Professor Jerzy Neyman also came and gave a lecture on maximum likelihood and other estimators. I liked Professor Neyman's style of presentation very much. He raised issues regarding consistency, efficiency and so on by asking questions and then pointing out deep logical flaws in some of the obvious "answers." Such interactive exchanges with the audience continued without any notes while Professor Neyman paced up and down. His forceful seminar was so impressive.

Mukhopadhyay: Were there something like "student seminars" too?

Mardia: I remember that "linear programming" was not included in the masters curriculum. I started

reading about linear programming and constrained optimization by myself. Later I gave a talk on this topic in the “student seminar” series. Senior masters students often took part in the “student seminars.” These gave students important exposure and some good practice in talking in front of a audience and answering questions.

During this formative period I learned some important lessons: everything we read in print was not necessarily correct and I also understood that some results printed in books or research papers could be extended and sharpened. These realizations gave me the confidence and hope for future creative work.

Mukhopadhyay: The University of Poona is not far away from the University of Bombay. Did you see any interactions among the statisticians at these two sister institutions in the mid- to late 1950s?

Mardia: I do not recall any major interactions. I thought that the University of Bombay had the most reputable group of statisticians and they were the leaders in that geographical area. My memory has faded about the specifics of Poona’s statistics program. The University of Bombay used to invite some external examiners from Poona, I am sure.

A TASTE OF THE REAL WORLD

Mukhopadhyay: After receiving the M.Sc. degree in statistics in 1957, what was in store for you?

Mardia: Overall, the two years at the University of Bombay were great. I did not, however, do too well in the examinations. Again I partly botched the “practicals.” When I graduated from the university, the State Bank of India was hiring people after screening through their highly competitive examinations. Many bright individuals sat in those exams with the hope that they would be selected. Some of my classmates ranked high enough in the examination and succeeded in getting jobs in the bank. I applied for a position too, but I was not selected! Now I may add that *fortunately* I was not selected! (Laughs.)

At that time, I did not aim for an academic career. Incidentally, I became very close to Professor Chakrabarti. I went to his house a number of times and he used to offer delicious Bengali munchies and snacks. Apart from the statistical discussions and help I got from visiting him at home, I admit that those delicious snacks were major attractions too. Babubhai Shah started working with Professor Chakrabarti on a Ph.D. thesis topic. My parents were hoping that I would take up a real job, earn a living and settle down in life. I was hesitant, but Professor Chakrabarti was advising me to pursue a Ph.D. degree in statistics.

Mukhopadhyay: You came in contact with Professor P. Masani. How did that happen and where did this connection lead you?

Mardia: I was not getting any job offers and I was already wondering about joining my family-run business. Professor Chakrabarti asked me to go and see Professor Masani, whose office was almost next door. He was Head of the Department of Mathematics. When I went to see him, he became excited and wrote me a letter offering a teaching position. He wanted an immediate reply. I was not too sure about an academic career at that point. But Professor Chakrabarti told me that if I ever wanted to pursue a Ph.D. degree or seek opportunities overseas, then I would be better off in the future if I accepted this offer from Masani. I decided to accept this one-year offer and started to teach.

Mukhopadhyay: This was a big break for you then. Any other recollections about those days?

Mardia: Professor Masani was very well known for his diligence and hard work. He would work day in and day out without letting up. He told me to get a solid foundation in mathematics including measure theory. I started learning the material from him. During my childhood, I had solved many challenging puzzles. When I grew up, I became more interested in finding what is in a “theorem” rather than proving the “theorem” itself. Professor Masani taught me proofs of very many deep theorems in measure theory, but I wondered about their inner meanings and beauty. The Institute of Science had connections with the prestigious Tata Institute of Fundamental Research (TIFR.). Professor Pitt came from Nottingham University to visit TIFR and gave some lectures on measure theory which later shaped his book, *Integration, Measure and Probability* (1963). I attended those lectures very seriously but there was no fire. I did not get too excited and that puzzled Professor Masani.

In addition to my regular duties of teaching both mathematics and statistics, I also sometimes substituted in Professor Masani’s classes. Professor V. Mandrekar of East Lansing was doing his B.Sc. degree in mathematics in this Institute. In his first year, I had him as a student in my class.

Incidentally, you will recall that Babubhai Shah was in the other building in the university. He was already doing research in the design of experiments and I would regularly exchange ideas with him. For some time, I was interested in Pareto distributions and distributions of a range and other related problems. I also got some partial results. But I was not sure where my career was going.

CHANGES IN THE AIR

Mukhopadhyay: But you could sense that major changes were in the air, right?

Mardia: Yes, you are right. My family started getting impatient and wanted me to get married and get settled, and so on. I had been engaged since 1955 and that meant two years went by but I did not get married! Finally, I got married to Pavan in 1958 at the age of 23, which was considered “old” according to our custom. My younger brother also got engaged to be married on the same day so as to minimize his waiting time. (Laughs.)

I did not get any time to enjoy life very much. Immediately after I got married, I went back to the Institute and immersed myself in the studies of mathematics again. Professor Masani was planning to leave the Institute, probably in 1959, and go to the University of Pittsburgh. I seriously started to think about making a career move for myself. I applied for a position elsewhere. I vaguely recall that I got an opportunity to go to the University of Iowa, but for family reasons that did not materialize.

Mukhopadhyay: I guess that this was your period for job as well as soul searching.

Mardia: You are correct. I was looking for an opening to the right career path. Then I heard that Ruia College, another prestigious college affiliated with the University of Bombay, was looking for someone to teach statistics courses. I applied for this position and got the job.

Our first child, Bela, a daughter, was born in 1959. At that point it became very clear to me that I would go overseas if and only if it would be financially feasible for my family to accompany me for the trip. I taught in Ruia College during 1959–1961. Unfortunately I do not recall the specifics from that period, but I do remember that the head of the department and other colleagues were kind and helpful to me. Also, I decided to improve my background in pure mathematics by earning externally an M.Sc. degree from Poona University in 1961, where I topped the list. I studied everything by myself for three months or so for the examinations.

With one baby at home and another one on its way the hustle and bustle of the city life of Bombay started to take its toll on both my wife, Pavan, and myself. We decided to move away from Bombay for some quiet and peace. Without a Ph.D. degree it seemed nearly impossible for a visit overseas. By this time, I had written a paper on multivariate Pareto distributions (Mardia, 1962). I was gaining confidence and then the idea of seriously pursuing the Ph.D. degree crossed my mind.



FIG. 4. *Kanti and Pavan Mardia's marriage photo, Bombay, 1958.*

UNIVERSITY OF RAJASTHAN

Mukhopadhyay: Did you make a career move then?

Mardia: In 1961, Rajasthan University in Jodhpur was starting a separate statistics department and they were looking for qualified teachers in statistics. Its close proximity to Jaipur, where I had spent the first part of my college life, made this opportunity very appealing. I moved to Rajasthan University to start their masters degree curriculum in statistics. There was another appointment (Dr. B. L. Sharma) junior to mine and we both taught at the masters level. I was more responsible for formulating the curriculum. The acting head of the department was Professor G. C. Patni, from the mathematics department. He suggested that I should pursue a Ph.D. degree, particularly because I already had some publications. In 1961, our son, Hemant, was born.

I registered under Professor G. C. Patni as a Ph.D. student and the research work that I was doing myself was progressing well. More students were enrolling in the courses I was teaching. Professor B. D. Tikkiwal, who was well known in sampling theory, joined the department a year later. He wanted me to work under his supervision. But I was not about to work in sampling, and then tension started to build. On the other hand, Professor Patni was always more than gracious and kind to me. I had both good and bad fortune. When I first arrived, I seriously thought that I was going to retire there. But quickly my views changed drastically. I again went into the transition mode and started looking around for a position abroad.

Mukhopadhyay: You were a junior faculty member and your life was miserable. How did you come out of this tight corner?

Mardia: The Commonwealth Scholarships became available in 1964. Professor Patni encouraged me to

go abroad. The vice-chancellor of Rajasthan University was supportive of me. Because of their support, I applied and received one of the Commonwealth Scholarships. When I applied for leave without pay, I faced tremendous hurdles at the departmental level. Unfortunately, I could not persuade Professor Tikkiwal to help me this time.

COMMONWEALTH SCHOLARSHIP TO ENGLAND

Mukhopadhyay: There was a period when your mind was set for overseas travel, but you had not yet left India. What was going on around that time?

Mardia: Before I left India on a Commonwealth Scholarship with my family, I submitted my first Ph.D. thesis to the Rajasthan University. At the time of my departure from India, that Ph.D. thesis was being examined by eminent external referees. I came to know much later that Professor Henry Daniel from Birmingham University was one of the external examiners. My first Ph.D. degree came in 1965.

Mukhopadhyay: Where overseas were you heading as a Commonwealth Scholar?

Mardia: I left India with my family on September 13, 1964, on way to the University of Newcastle for a Ph.D. degree under the supervision of Professor Robin Plackett. He was well known for contributions in linear models and design of experiments. He was very knowledgeable in all aspects of statistics.

I was in a large group of Commonwealth Scholars from India in different subjects. The group was given a high profile reception upon arrival in London. The Mayor of London came to welcome the scholars. We went through a series of receptions and orientations lasting nearly ten days. Hemant was three and Bela was five. We stayed in a good hotel but there was no real facility for vegetarian meals. We were tired and waiting for the day to go and settle in Newcastle, the final destination.

Mukhopadhyay: I gather that you reached Newcastle after spending about two weeks in London. Did you adjust to the new surroundings and culture quickly?

Mardia: We got the culture shock of our life! We stayed temporarily with a host family arranged by the British Council. In this host family, the husband was Indian and the wife was English. Our children were hungry by the time we arrived at their residence. Fruits were on the table but these were refused to the children. Apparently, there were appropriate times to eat fruits! It was the wrong time to get hungry. I remember the incident vividly. This period was very trying.

Soon a representative from the British Council took us to a place where we could live more permanently as a family. Nearby, there was another Indian family, Ghura, who showed us around. They were very helpful. We immediately moved in and became very close to the landlord and his family. What a relief and joy it was to eventually find a place where we could buy Indian spices and groceries! I still remember the first home-cooked meal in a foreign land after missing it for over three weeks. We lived in this one place for as long as we stayed in Newcastle. Subsequently, due to the children's schooling we came in contact with a much larger community.

UNIVERSITY OF NEWCASTLE

Mukhopadhyay: In the University of Newcastle, which department did you join as a student?

Mardia: I went to the Department of Mathematics, which had a section on statistics. Professor Plackett, my assigned advisor, was Head of the Department of Mathematics. He was probably Editor of the *Journal of the Royal Statistical Society, Series B*, right around this period. He was a very busy man but he always had time for me. I became a full-time student all over again.

Mukhopadhyay: Did you think ahead about possible topics for a Ph.D. thesis?

Mardia: Professor Plackett and I were exchanging ideas. He had just finished a paper (Plackett, 1965) where he formulated a bivariate family of contingency type distributions and he gave me a copy to study. I quickly realized that the same family could have been generated by quadratics having unique roots which led to interesting conclusions. This paper of mine appeared in *Biometrika* (Mardia, 1967a).

Another problem which interested me all along was to find the joint distribution of two sample ranges obtained from bivariate random samples. I found simple expressions for the means, variances, and even the correlation coefficient between the sample ranges. The formula for the correlation coefficient was derived earlier by H. O. Hartley in *Biometrika* (1950) but my answer did not match with his and so I was puzzled. My paper (Mardia, 1967b) was published in *Biometrika* where I wrote that Hartley's expression of the correlation coefficient was wrong! (Laughs.) Later, H. O. Hartley published (1968) a note with W. B. Smith, one of his students, showing that his formula was not wrong. It turned out that my approach was just simpler. (Laughs.)

Mukhopadhyay: So I suppose that no serious harm was done.



FIG. 5. Left to right, Mrs. Brook, Kanti Mardia, Robin Plackett, Pavan Mardia, and Mrs. Plackett, at Newcastle, 1966.

Mardia: (Laughs.) Right, no serious harm was done. Another work of mine that has survived all these years had to do with a nonparametric test for locations in a bivariate distribution (Mardia, 1967c). This work was also done in the University of Newcastle.

Mukhopadhyay: Did you take any courses? How was the Ph.D. program structured?

Mardia: I did not have to go through any course work. I began exploring various research problems right away. Students were expected to attend regular colloquia. I remember that one time George Barnard came and gave a lecture. There was a symposium once where I presented a paper and I think that O. Barndorff-Nielsen was present.

Mukhopadhyay: You went to Newcastle with a wealth of knowledge about statistics. How did you proceed to learn new techniques and areas?

Mardia: In the beginning, my thesis topic was quite open. I had frequent discussions with Professor Plackett. He guided and exposed me to a broader horizon. It was the time when I started learning more things directly from the published papers. I was attracted by H. Chernoff's and E. L. Lehmann's nonparametric papers.

I kept researching by myself and I was totally independent. They had the KDF9 computer which ran on the language called ALGOL. I began having some difficulty working with this machine. Professor Plackett was persistent that I must learn this language and eventually I became quite efficient in programming. I used computing tools extensively for my work in nonparametrics.

I also attended some of the Royal Statistical Society meetings. The invited papers with discussions always fascinated me. I heard some lectures of Vic Barnett and Toby Lewis on extremes. I commented (Mardia, 1967d) on their paper, but I had to do so within five minutes of allotted time, something very new to me. In



FIG. 6. Kanti Mardia received the D.Sc. Degree, at Newcastle, 1973.

the middle of my comments, the bell started ringing. It was a very shaky but unique experience! (Laughs.)

Mukhopadhyay: Eventually what turned out to be your thesis topic in Newcastle?

Mardia: I already had two papers in *Biometrika* (Mardia, 1967a, b) and another two in *J. Roy. Statist. Soc. Ser. B* (Mardia, 1967c, 1968). I finally wrote my thesis on "Some contributions to bivariate distributions and nonparametric methods." This work was finished in approximately one and one-half years, but I did not know what to do after getting the Ph.D. degree and so I stayed on for a while. I passed my final thesis defense in January or February, 1967. Meanwhile, the two children were growing and my wife, Pavan, was pregnant with our third child. We had a baby girl, Neeta, in March, 1967.

For my Ph.D. thesis examination, the external examiner was Allen Stuart. This was the first time I met the "Stuart" of the famous "Kendall and Stuart." He asked me pertinent questions and then kindly suggested how I might move ahead in different directions for further research. In the end, he remarked, "Two Ph.D. theses could have been made out of this one thesis." I felt honored by the fact that this praise came from someone like Allen Stuart.

Mukhopadhyay: After finishing the Ph.D. degree, did you contemplate going back to India?

Mardia: I was thinking about this. But then Professor Tikkiwal from India hinted that when I returned to India after fulfilling the terms and conditions of the Commonwealth Scholarship, I would be transferred to

teach in an undergraduate college. I felt unbelievable pressure building upon me from so far away!

Again, I heard the call for drastic changes in our lives. Some major decisions were hanging in the balance and I had to make a “statement.” A lecturer’s position became available in Newcastle and Robin advised me to apply. I went through the process, but the official waiver of my obligations to India arrived much too late, and hence I could not be offered a position. Robin asked me to withdraw my application and I followed his advice.

UNIVERSITY OF HULL

Mukhopadhyay: You then applied to the University of Leeds and what happened next?

Mardia: Once I got all the clearances from the Government of India, I applied for a position in the University of Leeds, probably in January or February, 1967. But, I was not selected. (Laughs.)

Meanwhile, I got an interview with the University of Hull for a lecturer’s position. Hull is on the east coast of Britain, about sixty miles from Leeds. I liked everything in Hull. In April, 1967, I joined the statistics section in the Department of Applied Mathematics. They had two lecturers, Jim Thompson and Edward Evans. Jim worked with J. L. Hodges, Jr. and came from Berkeley. Edward worked on entropy but later switched to statistics. Subsequently, Michael Bingham, a student of K. R. Parthasarathy from Sheffield, was hired. This was a very good group.

Mukhopadhyay: I hope that your move to Hull was smooth.

Mardia: We bought a house straight away and arranged schools for the two older children. Our infant daughter Neeta came down with a bad strain of whooping cough and she was quarantined. The initial period was rough. After I had been a few days in the department, Professor Slater, the in-charge, asked me to describe the location of my house. I described the exact location and then Professor Slater said, “Kanti, would you believe! Your house is exactly opposite my house.” I thought to myself, “Oh God!” (Laughs.) One can surely guess that Professor Slater did not drive and frequently I gave him rides! (Laughs.)

Mukhopadhyay: What courses were you assigned to teach?

Mardia: I taught multivariate analysis to third-year students and had a very large class of second-year students. So I prepared my own lecture notes and adjusted the teaching style accordingly. I remember

being asked to teach some traditionally unpopular courses, but those were extremely successful when I taught them. I also taught statistical inference to third-year students and some of my initial Ph.D. students came from this course. I was strengthening as well as teaching the department’s course offerings. At the same time, my own research program started to flourish.

Mukhopadhyay: Did you then handle both the undergraduate and graduate students in Hull?

Mardia: The two systems in the United States and England are quite different. In England, one does not customarily go through a rigid course work in a Ph.D. program. One may opt to enter a Ph.D. program right after finishing an undergraduate degree. A third-year undergraduate in statistics learns through courses and substantial honors project, many modern aspects of statistical theory and applications. A student with such preparation and maturity is normally guided by a supervisor to explore research topics that may later develop into a Ph.D. thesis. This process may need about three to four years to culminate into a Ph.D. degree.

Mukhopadhyay: Kanti, I realize that you went to Hull as a lecturer with substantial experience. Were you happy?

Mardia: Not exactly, but I had no choice. I felt bothered mentally. I started looking for a more suitable position elsewhere in 1969. A senior position became available in Hull and Toby Lewis joined as Professor of Statistics, with the understanding that he could immediately hire a senior lecturer. I applied for the position. Obviously there was some competition but, in the end, I got the senior lectureship.

Mukhopadhyay: As you looked for a right position, did you ever consider moving away from England?

Mardia: The racial overtones and related flareups now and then in England bothered me greatly. I also wondered about the prospect of my eventually becoming a professor in England and worried that the chance was nearly zero. I could think of only K. R. Parthasarathy who became a professor in Sheffield.

I started looking for an opportunity to go abroad. In 1969, Madan Puri made arrangements to get me an offer from Indiana University, Bloomington, to become a nontenured associate professor. But, having heard horror stories about nontenured positions, I started negotiating with them and later decided that I was not about to go to Bloomington with my family with a nontenured job. That offer fell through.

Mukhopadhyay: So you stayed in Hull, I presume. What came next?

Mardia: The position of a reader is reserved only for good scholars. Monetarily this position is not very different but it has a lot of associated prestige. Each university in England has a unique system outlining the process of appointing readers. I was interviewed for the readership position in Hull with David R. Cox as the external and I became a Reader in 1971. I stayed in Hull through August 1973.

Mukhopadhyay: What were some of the research topics of your Ph.D. students in Hull?

Mardia: Barry Spurr worked on tests for multimodal axial circular distributions (Mardia and Spurr, 1973). This developed nonparametric methods that later became a part of directional data analysis. Another student, T. W. Sutton, had worked on blocking problems in meteorology and regression analysis on a cylinder with temperature as a variable (Mardia and Sutton, 1975). This work needed methodologies for some distributions with cylindrical variables and so this student developed both parametric and nonparametric methods for cylindrical distributions (Mardia and Sutton, 1978). In the University of Hull, I essentially focused on guiding these two Ph.D. theses.

BOOK WRITING AT THE UNIVERSITY OF HULL

Mukhopadhyay: Kanti, you are well known for your books and edited volumes in a variety of areas. How and where did all these begin?

Mardia: The first thing I ever published that I could call my own was a short story written in Hindi for the college magazine in Bombay. The serious book writing started in Hull.

Recall that Allen Stuart was the external examiner for my Ph.D. thesis in Newcastle. He saw the great potential in my thesis area and mentioned that there was no book dedicated solely to that subject. Allen suggested that I should write a book on bivariate families of distributions. He said that his former student, Keith Ord, was writing the univariate part (Ord, 1972). So, I immediately started writing the book, *Families of Bivariate Distributions*.

Allen was Editor of the Griffin's Statistical Monograph series and he urged me to finish the manuscript quickly. From time to time he would call and ask about my progress. The project was moving along very slowly. After a while, he said, "Kanti, look, there is no perfect book. I will tell you an anecdote which you should always remember. Harold Hotelling once had

a contract with a publisher to write a book on multivariate analysis. He started writing some chapters and some years went by. At the end of each year, when the publisher inquired about the progress, Hotelling reported which chapters he was writing or revising and so on. During this time, C. R. Rao's biometric research book (1952) and T. W. Anderson's multivariate analysis book (1958) came out, and Hotelling felt that there was no more urgency for another book on multivariate analysis. Kanti, don't fall in such a trap." Allen said, "The moral is this: do not wait for someone else to write "your" book in your subject!" (Laughs.)

I took Allen's advice very seriously. I moved on with this project, collected all the necessary materials quickly, and I completed the book in about one and a half years. My first book, *Families of Bivariate Distributions*, appeared in 1970 (Mardia, 1970a).

At the time when I wrote this book there was nothing else in the area. Then came the book of N. L. Johnson and S. Kotz (1972). Of course, the Johnson and Kotz series of books were superior.

DIRECTIONAL DATA ANALYSIS

Mukhopadhyay: How did you come upon the area of directional data analysis?

Mardia: In Newcastle, I began developing nonparametric methods by way of Hotelling's T^2 test. But, I was never too keen on working with ranks and asymptotics. In the latter part of 1964, I started thinking about some simple tests. I wanted to have a slick way of doing bivariate nonparametrics and not lose much power. I centered the two distributions, projected them on circles and worked with the uniform scores. Then I examined how these scores in the two populations were distributed. When I did this sort of thing fully in my thesis, I did not know anything about Geoff Watson's work on directional data. I did not even know what "directional data" was. Then Robin Plackett pointed out to me that there was a short note (Wheeler and Watson, 1964) proposing a test that came to be known as the "Wheeler-Watson test." That paper came to my attention after I had submitted my thesis in Newcastle and my paper (Mardia, 1967c) was published. It turned out that I had independently derived the Wheeler-Watson test.

Mukhopadhyay: Would you please explain briefly what this area is about?

Mardia: One may consider, for example, migrating birds and their homing directions. In this context, one may like to investigate whether there is a preferred

direction or measure the variation from the homing direction, if any. Most navigational problems and many problems in astronomy involve measurements with directions. There were quite a few data analytic problems involving directions. Usual statistical entities such as the sample average and sample standard deviation are not so meaningful when observations are directions. One must take into account the geometrical structure and topology in order to arrive at appropriate analysis of such data.

Mukhopadhyay: Who were some of the major contributors in this field?

Mardia: Of course, R. A. Fisher did some early and fundamental work on the dispersion on a sphere (Fisher, 1953). Geoff Watson was probably the next most important contributor to this field. His students (e.g., Michael Stephens and Rudy Beran) wrote theses in this area. Also, J. S. Rao wrote his thesis in 1969 on directional data at the Indian Statistical Institute, Calcutta, under C. R. Rao.

Mukhopadhyay: Did your directional data book originate in Hull?

Mardia: Yes, it did. As I was writing the bivariate distributions book, I felt that I got in me the bug of writing books. (Laughs.)

Substantial amount of material was available, but this material was all scattered. It was time to make a synthesis of the papers and dissertations and present this in a more accessible form. My research students and I were collecting these materials, and I thought that I already had enough for a book. Thus, the book on directional data was born.

Mukhopadhyay: How did you proceed?

Mardia: I wrote to Eugene Lukacs, an Editor for Academic Press for the series on probability and statistics, explaining my intent. Then, following Allen Stuart's valuable advice given to me before I wrote my first book, I immediately moved forward with the project with full steam. Toby Lewis was very supportive and he asked me how much time I needed to finish this book. He first approved a one-term sabbatical, followed by another, which were both immensely helpful for concentrating on book-writing. Some of the works on spheres were either incomplete or not very satisfactory, and so I started developing the needed material as I went along. By that time, my second sabbatical was gone and Toby suggested that I finish the book with whatever available material there was. Otherwise, the work could have dragged on much longer.

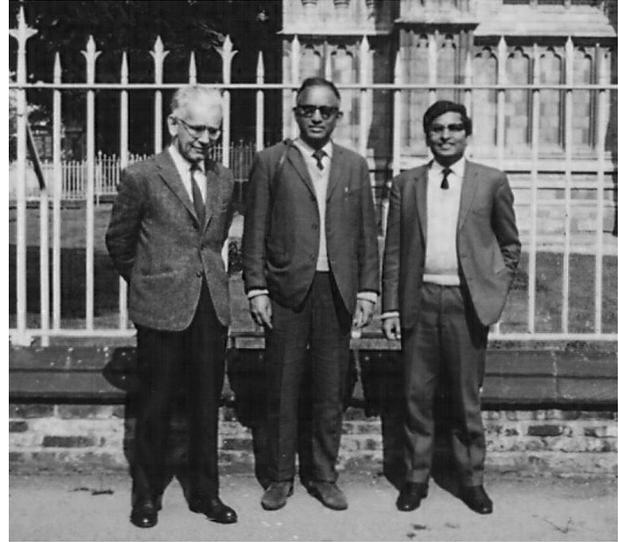


FIG. 7. From left to right: E. Lukacs, D. Basu, K. Mardia, at Beverly Minster (near Hull), 1971.

I finished writing the book in 1971. The *Statistics of Directional Data* was published in 1972 and it was an immediate hit. Geoff Watson (1973) wrote a very nice review of that book.

Mukhopadhyay: This book included a number of valuable tables. You produced several tables yourself. But you had to expend quite some energy to get permission to reproduce some of the other tables. Do you want to mention that story?

Mardia: This book needed many tables and I requested permission from Michael Stephens to reproduce some of the tables from his published works. He was hesitant because he was also writing a book in the same area. As many of those tables were from the journal *Biometrika*, I then approached its Editor, E. S. Pearson, for permission to reproduce the tables. Pearson said that Michael Stephens could be justified in being hesitant and he hinted that there could be a conflict of interest here because some of these tables were going to be included in the forthcoming E. S. Pearson–H. O. Hartley (1972) volume. He was not too sure that he should give me a “go ahead.” I was kept in suspense while I waited with an almost finished book!

I had lot of correspondence with Pearson regarding my directional data book including many exchanges among Michael Stephens, Pearson and me regarding the copyright issues in reproducing some of the tables published earlier in *Biometrika*. Toby Lewis suggested that I go and see Pearson personally. I may add that I met E. S. Pearson only once, probably in 1970 or 1971, in his office in the University College, London.

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Editor of Auxiliary Publications
Professor E. S. Pearson

TELEPHONE
01-397 9244

2 June 1970

Dear Dr Mardia,

Many thanks for your letter of 4 May which I found on return from the U.S.A. Let me summarise some points in reply.

- (1) It appears that the University of Colorado is or just has produced a Table, prepared by Vogel and Norton. It is said to give 5 figures for % points of $F(P|v_1, v_2)$ as follows:
- $v_1 = 1(1)10, 12, 15, 20, 24, 30, 40, 60, 120, \infty$
 $v_2 = 0.1(1)2, 22, 25(0.5)5, 6(1)10, 12, 15, 20, 24, 30, 40, 60, 120, \infty$
 $P = 0.0001, .001, .005, .01, .025, .05, .10, .25, .50, .75, .90, .95, .975, .990, .995, .999, .9999$

The Table is said to cover 62 pp. with a 27 pp. Introduction. I have not seen a copy, only had a summary from D.B. Owen of Dallas, who is chairman of the I.M.S. Tables Committee.

- (2) Your results are clearly more extensive, because they cover fractional v_1 values and for other reasons. I don't know whether you have estimated how many pp. the ^{table} covers or what plans you have for publication. It might be impossible to get any journal to print it.

- (3) Hartley and I have nearly finished our preparation of Vol. 2 of Biometrika Tables for Statisticians, and could not possibly include anything of this size. What we could do, and I would favour this, would be to squeeze in a brief 2 pp. (possibly by cutting out something else).

It occurs to me that a page of 5% + a facing page of 10% points easing interpolation in the top left hand corner of the F-table would be quite valuable. A possible scheme

(a)

for such a 2pp. table is enclosed. You may have a better suggestion.

- (4) Possibly you would not want to extract a portion of your work in this way, but I would personally be very ready to make such an inclusion if you were willing. Of course it may be a long time before your programme is complete, and if we were to include these 2pp. in Biometrika, Vol. 2 I would need the results before the end of the summer.

- (5) Incidentally we are including Meinymton & Thompson, 1943 Biometrika F-table in the Volume. D.E. Arnos of Sandia Corporation checked it for us, and found a number of errors, mostly of 1 unit in last place, see Biometrika, Vol. 57, pp. 211-12.

Your sincere
E.S. Pearson

(b)

FIG. 8. (a) A sample of E. S. Pearson's letter on K. Mardia's F -tables with fractional degrees of freedom. (b) The last part of E. S. Pearson's letter.

When I saw Pearson, I sensed that he was not very comfortable with the whole episode and he was not happy about how the events turned out and became so complicated. He was a very kind person. By that time, I had become quite proficient with computers and I was preparing tables of the F -distributions with fractional degrees of freedom. So I dropped the hint that Pearson could include some of my F -tables with fractional degrees of freedom in the upcoming Pearson-Hartley volume. He then suggested that I should recalculate Stephens's tables as much as possible, but he would permit me to reproduce the difficult parts of his tables. My F -table was inserted on pages 171-174 of the Pearson-Hartley (1972) volume.

Mukhopadhyay: It sounds like a very high level negotiation!

Mardia: It was understandable, but frustrating nonetheless. Again, Toby's advice came in so handy.

The interesting thing is that Nick I. Fisher, Toby Lewis and B. J. J. Embleton (1987) later wrote a book that dealt with the spherical data. I am very glad that they came up with their book, which included many details of the associated exploratory analysis. This book beautifully supplements what was lacking in my 1972 book.

Mukhopadhyay: What else was going on during this period?

Mardia: Meanwhile, the children were growing up. My wife, Pavan, already had a masters degree before we came to England, but she was not getting any suitable jobs. Pavan wanted to teach mathematics in a school. In 1969, she went through the three-year full-time certification program for education. All of us in the family had to endure a long and busy period. It was delightful when Pavan became a permanent school teacher in 1973, in Leeds. To her credit, she maintained the stability in the family through the whole ordeal.

A number of interesting people lived in the same neighborhood where we lived. One of them was Alan Plater, a very well-known playwright. The BBC often broadcast his plays. His son and my son, Hemant, were classmates in school. Phillip Larkin, a great poet, was the Chief Librarian at the University of Hull. Also, Sheldon, a novelist, was Larkin's second-in-command. These contacts with literary people were lots of fun for both my mind and soul.

CHAIR PROFESSORSHIP OF APPLIED STATISTICS, UNIVERSITY OF LEEDS

Mukhopadhyay: You were settled in at Hull. Why did you then decide to move?

Mardia: I liked Hull very much and I enjoyed doing what I did there. But, even so, for some time I was itching to become a full professor and worrying about my chances to hold such a position. One time Toby (Lewis) jokingly said, “Kanti, you don’t move to the Sahara Desert simply because someone from there offers you a professorship. Take it easy and don’t get so worked up. In time a position will come along anyway.” Toby was correct and I did not even have to move to “Sahara.” (Laughs.)

In the United Kingdom, some universities have a system which awards “personal” Chair positions and only exceptionally qualified individuals can be promoted to a Chair. The personal Chair Professors normally are not administrators, although there are some exceptions. The University of Hull did not have this system of personal Chairs. It was clear that I would have to move in order to become a full professor.

In 1973, some of these positions were openly advertised and I applied. There were positions both in Salford, which is close to Manchester, and Leeds. I was offered a Chair Professorship at both Salford and Leeds. When I started my career in the United Kingdom, the University of Leeds did not offer me a junior position, and so I did not think twice! I decided to join the University of Leeds. (Laughs.)

But seriously speaking, there were important reasons to move to Leeds. Barnard Welch who had worked, among other things, on the Behrens–Fisher distribution of the two-sample statistic and robustness, was the Professor and Head at Leeds. This was a good department and I thought that I would never have to be the Head because there would always be two Chairs in the department. The Vice-Chancellor Lord Boyle, who interviewed me, had great sympathy and regard for Indian scholars and other minorities. He was a former Cabinet Minister of Education and held very broad ideals. In Hull, Toby Lewis was very supportive and he was one of my referees. My colleagues in Hull understood fully that this was a career move for me, and they all helped and supported me throughout the ordeal, for which I remain grateful.

The offer from Leeds came in May, 1973, and I joined in September of that same year. The position came with a personal secretary and a statistical assistant. A Ph.D. student, Dick Gadsden, had followed me from Hull to Leeds. He worked with me on sequential methods for directional data. He is now a senior lecturer in Sheffield, in the same department as Gopal Kanji.

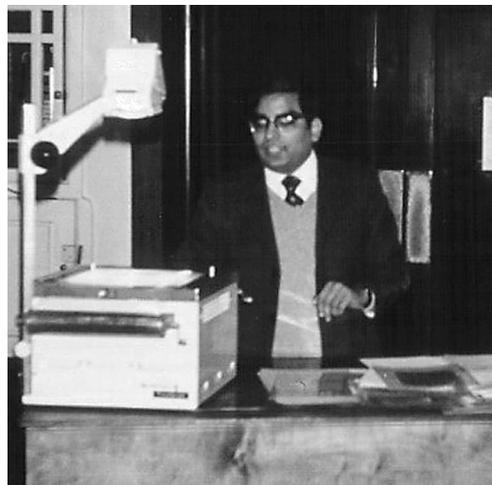


FIG. 9. Kanti Mardia presenting a Discussion Paper at the Royal Statistical Society, London, 1975.

Mukhopadhyay: What were you doing when you first arrived in Leeds?

Mardia: I started with a statistical assistant who helped me with the computer programming. Peter Zemroch was my student and then he became my research assistant in Hull. He had also moved with me from Hull to Leeds. I had a grant from the Science Research Council to construct the tables for F - and related distributions. I already had a contract with Academic Press to write the multivariate analysis book. I was very busy with research problems in directional data, as I was preparing a paper to be read at the Royal Statistical Society meeting in 1975.

Mukhopadhyay: Why were you so involved with the F -tables?

Mardia: I was fitting univariate distributions using the first four moments. This exercise needed F -tables with fractional degrees of freedom.

In Hull, I got the idea of writing on multivariate skewness and kurtosis for testing multinormality. This was conceived via multivariate linear model and permutation tests. The second moment in a permutation test depends on the multivariate kurtosis. I gave most of the details in my *Biometrika* paper (Mardia, 1970b). Then I got down to the F - or beta distributions and I needed extensive sets of F -tables for checking the goodness of the fitted distributions. Peter Zemroch developed the computer programs in ALGOL60 language and eventually Peter and I published a monograph, *F-Tables and Related Algorithms* (Mardia and Zemroch, 1978), which has since been translated into Russian. Peter continued working on algorithms for directional data for about three years and we published some joint papers.

Mukhopadhyay: What else was going on during those initial years in Leeds?

Mardia: After we moved to Leeds, Pavan got a job in a school right away. Our son received scholarships to attend a prestigious private school. Our daughters were progressing beautifully. In the family front, everything felt just right for a change.

In the department, I was given the responsibility for the masters program. To energize the curriculum, I introduced new courses. Apart from adding a course on directional data, I pushed for more vocational courses. Geostatistics and statistical computing courses were added around 1975. A set of new computers arrived in 1977 to modernize the computing environment.

I started the statistical consulting component to foster collaborative research with scientists from other disciplines. The routine consulting requests were passed on to the postgraduate students and they learned what real statistics was all about. Substantial consulting projects were shared by colleagues for broadening the scope of research in other fields and also for preparing grant applications.

Barnard Welch and I overlapped for about three years while he was preparing to retire in 1976. He lost interest in the day-to-day administration of the department. He was, however, still teaching. Outside of statistics, one of his main interests was the game of cricket. He often said, "I recommend retirement to do other things full-time."

I was brought to Leeds with the charge to energize the teaching, research and consulting programs. I started doing just that with vigor and vision for the future, I hope. I got the support I needed from my colleagues and the higher administration alike.

Mukhopadhyay: What was the administrative structure and who were some of your colleagues in Leeds?

Mardia: The statistics department was, and still continues to be, one of the three autonomous departments within the School of Mathematics. The school had a chairman and these three departments had respective department heads.

Apart from Barnard Welch, we had Harry Trickett who was a senior lecturer. He did some research in statistics, but his strength was in administration and teaching. Harold Peers had worked on invariance. I had also other colleagues. We had people working on, for example, distribution theory and time series analysis.

Mukhopadhyay: Between a department head and the Chairman of the School, who is more powerful? Where did you fit in this bigger picture?

Mardia: The department heads are traditionally more powerful. The role of the Chairman of the School is to coordinate its total program and services. If conflicts or duplication of programs or services arise among the departments, the school chairman then intervenes to mediate and guide all parties to a common ground for the benefit of the school. A department head is responsible for running the department, whereas the school chairman acts as a liaison.

When I arrived in Leeds, I found a wonderful administrative structure. I did not have to worry at all about the undergraduate administration. The school had a Director of Undergraduate Teaching who looked after all courses and related matters in the three departments. Each department was, however, responsible for formulating its own curriculum requirements, develop teaching modules, update future planning, and so on. I introduced tutorials with smaller groups of students and added modern course materials; for example, we created an exploratory data analysis course as a requirement for the third-year students.

Mukhopadhyay: In the mid-seventies, the university had to endure serious financial hardship and I am sure that your department had to streamline its priorities. How did you "reposition" yourself?

Mardia: There was a period in 1976 when circumstances changed and finances became hard to come by. I had to become the department head, quite reluctantly, to lead the group of ten statistics faculty members. Subsequently, I was allowed to hire new faculty members.

In the meantime, I received a large Symposium Grant. With this grant, I could invite short-term visitors from abroad to Leeds for collaborating on projects related to directional data. During that period, C. G. Khatri came to Leeds when my joint works with him started. Subsequently, O. Barndorff-Nielsen, Rudy Beran, Kit Bingham, Tom Downs, John Kent and J. S. Rao came to visit Leeds. John Kent was a graduate student of David Kendall and later he joined our department as a Lecturer. Ian Dryden also joined the department subsequently. It turned into a wonderful period to move ahead in the areas of directional data and non-Euclidean geometry in statistics.

Mukhopadhyay: I understand that in Hull, your multivariate analysis book was also conceived. When you moved to Leeds, work on that book continued too. What do you recall?

Mardia: The work on my multivariate book was continuing. When I was in Hull, Toby Lewis pointed out that John Bibby from St. Andrews was writing a book on the same topic, and I took John Bibby as

a coauthor. But slowly I came to understand that his style was very different. I first rewrote and verified everything he used to send. Then I took John Kent as another coauthor to make real progress. The *Multivariate Analysis*, jointly authored with J. T. Kent and J. M. Bibby, appeared in 1979, much later than it should have (Mardia, Kent and Bibby, 1979).

Mukhopadhyay: At some point, you went to Canada for a semester to try out a tenured position. Obviously you did not stay there. Would you care to comment?

Mardia: It was 1977. Racial tensions in the United Kingdom were on the rise. Many politicians and other people were giving negative speeches. My wife, Pavan, said “Let us get out of this country before it becomes too late for us.” We were seriously debating whether we should permanently move away from the United Kingdom and around that time I received an offer from the University of Windsor, Canada, for a tenured position. I thought that I should try out this change of venue for a semester. In January, 1978, I arrived in Windsor, Canada, by myself with a leave of absence from Leeds.

This was the coldest winter I had ever faced. Because it was the middle of the school year, my family could not join me. In Windsor, I was given a substantial teaching load. I was asked to teach a very elementary course with two hundred students! I had never taught any class nearly as large as this one. The departmental environment was very good and I liked my new colleagues. John Atkinson, who was the department head, and Dick Tracy were both very helpful. My family joined me in Windsor when they had the Easter break in the United Kingdom but the overall systems and cultures in the two countries were very different. My family did not take to it and deep down I also did not. It might have been different if my family had had more time to spend in Windsor or perhaps if I had not had to teach this heterogeneous and huge class as soon as I arrived. In May, 1978, I returned to Leeds. (Laughs.)

LEEDS ANNUAL WORKSHOPS AND CONFERENCES

Mukhopadhyay: You created the tradition of annual workshops in Leeds. You should feel genuine pride and satisfaction when you look back. Any highlights to share?

Mardia: If one wants to expose interested colleagues to a new subject, it works well to invite an

expert in that area and learn the subject from the lectures. For example, when I was writing the multivariate analysis book, I realized that the multidimensional scaling and Procrustes methods will have significant impacts on the area. John Gower (1975) had just published some work on Procrustes methods. I knew him from Hull, where I had invited him to a symposium on multivariate analysis which I had organized in 1973. I invited John to Leeds for detailed lectures on multidimensional scaling and Procrustes methods. A couple of other faculty members and I went through that workshop very diligently. Such workshops are now integral parts of the statistics department in Leeds. In subsequent workshops, I invited other scholars, including Julian Besag and Brian Ripley, because we felt that a lot of activity was imminent in spatial statistics and in image analysis. These gatherings are now internationally recognized as the Leeds Annual Statistical Research (LASR) workshops. We have an open-door policy. Anyone interested should feel free to participate at any time.

Also in 1985, Subha-Rao visited us and gave lectures on aspects of time series analysis that had direct bearing on spatial statistics. As early as 1979, we organized a conference in geostatistics. This was a workshop, but it was also open to several invited speakers along the lines of a conference. We had an invited speaker from France, A. Marechal (Centre de Geostatistique, Fontainebleau), from the G. Matheron group. This conference was quite a success.

In 1984, I organized a workshop on image analysis. This was the first time such a workshop had been held in a statistics department anywhere. Researchers from all over the world had showed a lot of interest in this workshop. One of the workshops on shape analysis was attended by David Kendall; Fred Bookstein also participated many times in these important workshops on shapes.

Our forthcoming workshop (the eighteenth one) will address spatio-temporal modeling with emphasis on applications. The applications will include tracking in machine vision, functional MRI in medical imaging and ecology. Some well-known statisticians (e.g., David R. Cox, Peter Bickel and Noel Cressie) have been invited. But there will also be experts in functional MRI, epidemiology, tracking and ecology. From Oxford, Andrew Blake (now with Microsoft, Cambridge) will participate. He is an expert on tracking. These annual workshops try to build a bridge of communication and collaboration among experts in statistics and other substantive scientific fields where fresh ideas and methodologies are urgently needed.



FIG. 10. From left to right: D. G. Kendall, P. A. Dowd, A. Marechal, K. V. Mardia. Geostatistics Meeting, Leeds, 1979.

Mukhopadhyay: Do you normally edit and publish the proceedings from these workshops and conferences? The proceedings can reach a much wider audience.

Mardia: In the beginning, we did not publish the proceedings. But, subsequently we started publishing these Proceedings starting in 1995 to reach a wider audience than the limited number of participants. These have been well received by the scientific community in general.

Mukhopadhyay: In your view, what have been your two best accomplishments in Leeds?

Mardia: I think that our department is recognized internationally. Our research program has been in the forefront of fundamental breakthroughs in information technology (IT). The department is undeniably on the map. I would like to think that I have helped in creating and strengthening this visibility. This has been the most important accomplishment. It has been such a gratifying journey for me.

Another major accomplishment, if I may say so, has been the modernization of our course offerings, including computer-aided teaching utilizing the latest available statistical software packages. A long time ago, in teaching our courses, we implemented our own software, even before the well-known software, MINITAB, came on the market.

Mukhopadhyay: Now please describe the worst episode during your tenure in Leeds in the sense that you would happily change your course of action right now if you could turn the clock backward?

Mardia: Very early on, the Science Research Council (SRC, now EPSRC) threatened our masters program. The SRC came up with a new policy to cut the number of courses in order to streamline programs



FIG. 11. From left to right: F. L. Bookstein, W. S. Kendall, K. V. Mardia, J. T. Kent, C. R. Goodall. The 15th LASR Workshop, Leeds, 1995.



FIG. 12. Workshop in action at home in Leeds. Playing bowls. From left to right: D. Terzopoulos, J. Koenderink, E. Berry, K. Mardia, L. Marcus.

across the university. I fought against this decision and made an appeal to the higher administration. All our M.Sc. courses were then reinstated.

But after three years of some calm and quiet, the SRC went back to the drawing board and decided to drop the M.Sc. program in statistics. Our Ph.D. program was hurt because our M.Sc. program fed students into our Ph.D. program and now that channel was eliminated! Difficult financial situations were knocking at the door. We lost some regular faculty members and some were replaced by temporary positions in order to cut costs. We continue having an active but smaller Ph.D. program. If I could turn the clock backward, I would definitely fight more to save the M.Sc. program.

Mukhopadhyay: Statistical methodologies have certainly changed focus over the years. In your view, where are we heading?

Mardia: During the periods of R. A. Fisher and P. C. Mahalanobis, statistics brought revolutions with

path-breaking applications in the areas, for example, of agriculture, biology and sampling, with great impact on population census and economic planning. In the past ten or fifteen years, new statistical ideas and methodologies have energized IT which is a general name to describe subject areas such as computer vision, image analysis and machine learning. In my department, we have a large group of internationally recognized experts in these and related fields. Fundamental challenges in data handling in IT have enriched the field of statistics tremendously. My feeling is that this change in emphasis and directions will continue in the foreseeable future. In Leeds, we have been preparing for such changes for quite some time.

HIGH PROFILE RESEARCH AREAS

Mukhopadhyay: Kanti, in your opinion, what are your primary areas of research expertise?

Mardia: Broadly speaking, the major thrust areas include multivariate analysis, directional data, shape analysis, spatial statistics and spatial-temporal modeling. Another big area, which goes hand in hand with these can be categorized as applications involving imaging, machine vision and so on.

Multivariate Analysis

Mukhopadhyay: Please highlight some of your important contributions in multivariate analysis.

Mardia: Classical multivariate analysis heavily depended upon the multivariate normality assumption of the parent population. I developed methods for checking multivariate normality (Mardia, 1970b) by introducing multivariate analogs of skewness and kurtosis and gave measures to quantify departures from normality. The impact of this paper has lasted more than that of some other papers of mine. When others come up with newer measures of multivariate skewness and kurtosis, they compare performances with earlier measures given in Mardia (1970b).

Mukhopadhyay: What do you suggest users do when multivariate normality is suspect?

Mardia: Unfortunately, I have not addressed that aspect. I would expect one to use multivariate Box-Cox transformations as a possible route. But it is not always an easy task to accomplish. One may alternatively use permutation tests for the mean or the location parameter. I wrote a related paper (Mardia, 1971) describing the effect of nonnormality on some multivariate tests and robustness to nonnormality in the linear model. In that paper I gave permutation tests which may provide plausible solutions.



FIG. 13. From left to right: C. R. Rao, B. Mandelbrot, K. V. Mardia, at Penn State, 1994.

Mukhopadhyay: What other kinds of multivariate problems attracted your attention?

Mardia: I have enjoyed creating new and interesting multivariate distributions and deriving some of their important properties. For example, I elaborated Plackett's family of bivariate distributions.

I worked on multidimensional scaling. The subject of multidimensional scaling helps one to come up with similarity measures. When I examine configurations, I can come up with numerical measures which will in turn tell us how similar or dissimilar these configurations are.

My 1977 work on how the singularity of the variance-covariance matrix Σ affects inference techniques involving the Mahalanobis distance has also been well cited in the literature. In Mardia (1977), I had defined what is known as the Mahalanobis Angle.

Perhaps the most important contribution was my 1979 multivariate analysis book, jointly written with John Kent and John Bibby which we talked about earlier. This book has met the test of time. My feeling is that a good book should last at least ten years. Some of my books, for example, the Families of Bivariate Distributions, have not been of this caliber. (Laughs.)

Mukhopadhyay: Since the early days of Fisher, Mahalanobis, Hotelling, Hsu, Roy, Bose, Rao and others, multivariate analysis has come a long way. Where will this field take us next?

Mardia: My best guess is that the field will become more exploratory and data oriented. There will be more emphasis on statistical modeling, for example through elliptic distributions, and in nonparametric or semiparametric models. There was a time when distributions were discarded as models if there were no analytical expressions for the maximum likelihood estimators of the parameters. That scenario has changed for the better. Model checking has become more a visual

art than anything else. With easy accessibility to computers, statisticians are now driven more by the complexity of the problems rather than opting for a narrow set of “nice distributions” for analytical reasons alone.

Directional Data

Mukhopadhyay: Now we move to directional data. Please highlight some of your important contributions.

Mardia: There were quite a few important problems involving directions on which I had the opportunity to work. I studied, for example, flying patterns of migratory birds (Mardia, 1975), various problems in geology, analysis of megalithic-yard data in archeology (Mardia and Holmes, 1980), and in astronomy the behavior of long-period comets (Jupp and Mardia, 1979).

John Kent and I had worked with Jim Briden, an earth scientist, on the formation of the earth, its various layers, continents and their movement patterns over time. The data reduces to the directions of the prevailing magnetic field of the earth, but sudden movements of some layers may change the course. Using the natural remnant magnetization in rocks, our work shows how to find out where a continent was located when a particular rock was formed and involves identification of linear segments given a set of ordered points. Our paper (Mardia, Kent and Briden, 1983) is highly regarded.

Once the magnetic components have been extracted, the objective is to follow the movement of the continents over geologic time—that is, the apparent wander paths. This problem was investigated with Dick Gadsen (Mardia and Gadsen, 1977). Also, a related problem is the movement of the area of vulcanism or hot spots. As the plates move, a chain of hot spots is assumed to be formed on the earth’s surface. Both can be viewed as following points along the arc of a small circle on the earth’s surface and thereby determining (fitting) that circle. We looked at the actual data for validation of the theoretical model. Further distributional work was developed with C. Bingham (Bingham and Mardia, 1978).

One time I worked with a physicist, Professor Alan Watson of Leeds, on high energy particles. It was believed that these particles could have arrived on earth from one of two possible galaxies. The question was whether these particles came from one single source. The points where these particles hit the earth may be thought of as a cap on a sphere. Jointly with Rob Edwards, I came up with an appropriate distribution and analyzed the observational data (Mardia and Edwards,

1982). I understand that the physicists’s postulates have since been modified.

Another project was on central place theory. Suppose that a town grows in a regular fashion. Then, using the principles of Delaunay’s triangle (Dryden and Mardia, 1998) for the set of sites of the towns, one should claim that these triangles should be equilateral. With Madan Puri and one of my students (Robert Edwards), we developed a statistical test (Mardia, Puri and Edwards, 1978) to check whether the triangles are equilateral. This work is again often cited and, in a way, inspired some shape work by others later on. We found the distribution of shapes of the equilateral triangles assuming that they were independent. But they were not really independent! More works followed later, including those by other researchers. If one looks at wind directions at two time points, they will be naturally correlated. The analysis of such data had led to another collaboration with Madan Puri (Mardia and Puri, 1978).

Mukhopadhyay: Your 1972 book, *Statistics of Directional Data*, was certainly major work.

Mardia: The directional data book has been a success. The field really took off after this book was out. My 1975 discussion paper, read at the Royal Statistical Society, also created much enthusiasm among researchers in this field.

Mukhopadhyay: Preparations for its second edition have gone on for years. Will it be out soon?

Mardia: P. R. Halmos once wrote that one should never go for a second edition of a book. But, Halmos himself published second editions of some of his works! (Laughs.)

I was hesitant to prepare a second edition of my book. Peter Jupp, who had a background in pure mathematics and differential geometry, later worked with me as a postdoc around 1976–78. He is now a Reader in St. Andrews. Peter and I have completely rewritten and updated the material. What one will find is a new book, *Directional Statistics*, which is expected to be out soon (Mardia and Jupp, 1999). The rewritten book took us close to eight years to finish!

Shape Analysis

Mukhopadhyay: Kanti, how did you get into the area of shape analysis?

Mardia: I have been fascinated by shapes, being brought up in the midst of the famous Jain temples with intricate marble carving (see Figure 2 of Mount Abu). I always wondered “How were these shapes generated? Are the replications accurate?”

Another exposure has been in childhood through palmists who would make claims based on various features of palms, for example, palm shapes. Apparently, there are seven basic types of palm shapes. This intrigued me—why are there seven?

Mukhopadhyay: Actually, you have been intrigued by palmistry for a very long time. Would you care to explain?

Mardia: When I was a small child, I was brought up with the expectation that I would pursue the family-run business, but a palm reader looked at my palm and forecasted that I would end up going abroad for higher studies. Notions like “higher studies” or “going abroad” were not even on the horizon. I have no idea how this palm reader could forecast my fate! (Laughter.)

Mukhopadhyay: Regardless of how the forecast was made, it turned out to be accurate. Where is that palm reader now? (Laughter.)

Mardia: I have also asked myself, “Where is that palm reader now?” Perhaps he should be invited to come and give some lectures in one of my workshops! That will constitute practical statistics on shapes! (Laughter.)

In fact, in 1980 I collected some preclassified palm shapes in the literature and constructed various landmarks to characterize the palm outline. I obtained what are now called Bookstein shape variables. It turned out that there is quite a large overlap between the shapes. I think that Ian Dryden also used this data in the initial period of his Ph.D. work.

Indeed, whenever there are claims related to “palmistry,” I try to get involved! There was an article in the *J. Roy. Soc. Medicine* (1990) by a medical doctor (Dr. P. G. Newrick) and his collaborators in the United Kingdom claiming that longevity depends on the length of what is called a life line. I got the data and analyzed it, but found that even the life line was not well defined (Mardia, 1991).

Scientific studies of ridge-patterns of the hand are important to detect genetic disorders and malformation. The field of scientific studies of such patterns is called dermatoglyphics. Now, there are various known features which are used to describe ridge-patterns. In the 1960s, L. S. Penrose—a Galton Professor—proposed a number of feature variables which are in use. I wrote a joint paper (Mardia and Constable, 1992) characterizing a unique special feature. We also provided software. Our proposed theory along with its computer algorithm have enhanced automatic recognition of fingerprints in forensic investigations (Mardia,

Baczkowski, Feng and Hainsworth, 1997). The software is slow but it does provide a unified statistical approach!

Mukhopadhyay: How and when did the actual transition to shape analysis take place?

Mardia: Fred Bookstein’s paper “Size and shape spaces for landmark data in two dimensions,” appeared in *Statistical Science* (1986) and I thought that this was the kind of paper that I had been waiting for quite some time. Fred’s paper showed me the light.

The following year, I believe, Ian Dryden came from Nottingham to Leeds to work on his Ph.D. with me. We started working on a joint project with an anatomist who had a problem which had originated from experimental breeding with mice. The anatomist started with big (heavy weight), average, and small (low weight) mice, and then let the breeding process go through some generations within the weight groups. One question was whether the shapes of mice, within a weight group, remained the same across generations. The anatomists were comparing shapes of the vertebrae of mice in each group. This is how I got into this area which gave me the impetus to start a brand new career, so to speak.

I should add that the subjects of shapes and directions are closely related. Ideas of constructing distributions are similar. In shapes, what was lacking was that there was no analogous “normal” distribution to work with. The question we faced was whether there could be an exponential family of distributions for shapes. In a series of papers, Ian Dryden and I considered the marginalization approach by integrating out the nuisance parameters (Dryden and Mardia, 1989, 1991; Mardia and Dryden, 1989).

Mukhopadhyay: These investigations eventually led to the distributions which are known in the literature as Mardia–Dryden distributions.

Mardia: I presented the distribution in my discussion of David Kendall’s 1989 *Statistical Science* paper. The distribution I proposed was clearly too simple for a problem that had seemed so intractable for some time! David liked the distribution but he did not believe the answer at first. Later, David validated the distribution using a stochastic formulation.

I worked as a catalyst. I got several people interested in a new and interesting subject. In turn, I was able to accomplish new results too, both theoretical and applied in nature.

Mukhopadhyay: You have not yet mentioned your recent book, *Statistical Shape Analysis* (1998), coauthored with Ian Dryden.

Mardia: Ian Dryden has been my colleague in Leeds since 1989. The book was finally launched as I was giving the special invited lecture on the same subject at the 1998 Joint Statistical Meetings in Dallas, Texas. I advised Wiley to print a large number of copies of the book. They did not take a statistician's forecast too seriously! (Laughs.)

It turned out that they ran out of copies within four months of publication. The reprinted version came out in April, 1999.

In shape analysis, there are many unsolved theoretical aspects. A shape or an image looks different when viewed from different angles or subspaces. If one rotates the axes or stretches or squeezes the axes, the basic characteristics of a regular shape should be preserved. For example, I considered projective shape space and the associated distributions. A theory paper, jointly written with C. Goodall and A. N. Walder, has appeared as Mardia, Goodall and Walder (1996). Walder was formerly my student and then he became a postdoctoral fellow. One of the fundamental challenges in the field of computer vision is to enable computers to "see," that is, to emulate human vision, and these projective invariants allow object recognition. This latter piece is a joint work with Colin Goodall which included machine vision applications (Goodall and Mardia, 1999).

Spatial Statistics

Mukhopadhyay: Another of your major interest is spatial statistics. How did this interest arise for you?

Mardia: Early on, I became interested in kriging within geostatistics and spatial statistics. I taught an M.Sc. course on geostatistics as early as 1978. I was charmed by the methodologies. Given some of the coordinates in a space, I was thrilled to learn how practical models were built with the help of variograms and covariograms. One could fit a surface, if nothing else was feasible.

I had a grant on geostatistics on which R. Marshall and I worked (Mardia and Marshall, 1984) to develop a spatial linear model under normality where the errors were correlated. The parameters were estimated by the maximum likelihood method. But there were some crucial difficulties. We had one realization from a stochastic process. We were not too sure whether we should proceed with asymptotics by increasing the size of the grid or by making the grid more dense. In other words, we were unsure whether we should "fill in" or "fill out!" Eventually, I thought that "fill out" should be the way to go because then the information would

steadily increase. We could obtain asymptotic results with complicated looking criteria under which the distributions of the parameter estimates were multivariate normal. One of my students, Alan Watkins, worked on multimodality, bias and other criteria in related spatial problems (Mardia and Watkins, 1989).

I am pleased to say that my 1984 *Biometrika* paper with Marshall is highly regarded in geostatistics. Here, we modified some of the classical ideas to come up with appropriate linear models in the new area of spatial statistics. Because of the general acceptance and popularity of linear models in statistics, I believe, our approach to spatial statistics with linear models has caught on rapidly.

Mukhopadhyay: Subsequently, you became more involved with research related to kriging.

Mardia: Yes, you are correct. John Kent's interest also turned to kriging. Fred Bookstein was working on comparing images. This involved comparing landmarks of two or more averages in the space. Suppose that we consider one plane in the (x, y) coordinate system and another one in the (u, v) coordinate system. The question may be whether these two planes are similar. If they are similar, then one should be obtainable by the identity mapping from the (x, y) to the (u, v) systems. But, if the two planes are not similar, then one may try to find the corresponding mapping of the plane in the (x, y) system to the one in the (u, v) system, and examine how deformed or stressed this mapping is if compared with the identity map. Fred did some important work (Bookstein, 1989) using thin-plate splines. One should bear in mind that this kind of mapping should not depend upon rotation or other similarity transformations of the shapes under consideration. Fred used thin-plate splines with linear terms which "kill" affine transformations. So one sees local shape changes.

This approach of Fred Bookstein helped to identify one kind of deformation. But in many applications, deformation may arise from a larger class which consists of kriging. Here, self-similar processes provide the necessary background. Then one may not only ask questions about the landmarks, but the tangent directions may also be included in our considerations. Fred had handled (Bookstein, 1996) this more general situation. This aspect of spatial analysis has a bright future.

Mukhopadhyay: I am quite certain that you have other ongoing book projects as we speak.

Mardia: I actually started writing another book on spatial analysis. When I introduced and taught the M.Sc. course on geostatistics, perhaps as early

as 1978, I prepared my own lecture notes. I was using those lecture notes instead of any book. In the meantime, Brian Ripley's *Statistical Inference for Spatial Processes* came out in 1981. Now I was in the same boat that Hotelling had been in his aspiration to write a multivariate analysis book! Even though I had a contract with a publisher to write this spatial statistics book, I could not see what purpose such a book would serve, particularly because Ripley had just written an excellent book on the same subject but also covering spatial point patterns. However, I lately have been actively writing the spatial analysis book with John Kent as my coauthor.

Mukhopadhyay: Sometimes, you have used Bayesian analyses. Are you a Bayesian now?

Mardia: Personally, I am a very pragmatic Bayesian. If there is prior information available, I tend to use it, especially in situations where there is no readily available better technique. I started relying upon Bayesian techniques when I began working on image and shape analysis. I do not see any practical value of using Bayesian techniques indiscriminately.

Applied Research

Mukhopadhyay: Methodologies you have been vigorously pursuing in spatial statistics, directional data and shape analysis are clearly in the cutting edge of statistical computing. Any thoughts?

Mardia: The images in general are very large and therefore techniques are developed which can use local contextual information. This is more so in low level image analysis where the aim is segmentation. Hence the use of Markov random fields as priors has come into use. On the other hand, for high level image analysis, such as in object recognition, structural information of objects in priors (e.g., deformable templates) reduces computational complexity to some extent.

In 1979, I attended a conference on geology in Paris where Paul Switzer gave a talk using some Landsat data and showed how he had classified types of rocks. It was delightful. I requested the data and he kindly gave it to me. The pixels had very low resolutions, perhaps $5 \text{ km} \times 5 \text{ km}$, I vaguely recall. The rock types were overlapped. At that time most statisticians had not even heard about pixels. (Laughs.)

I got some work done and submitted the paper to the *J. Roy. Statist. Soc. Ser. C*, but the referee did not like my work. I got an impression that the referee thought this approach of mine would go nowhere. But I felt otherwise. Soon, Paul Switzer presented a related

paper at the International Statistical Institute meeting in 1983 where Julian Besag was one of the discussants. Besag (1986) later pursued the iterated conditional mode approach. Geman and Geman (1984) on the other hand took the statistical computations to another level by exploiting the ideas of stochastic relaxation and Gibbs distributions. Now these are labeled Markov chain Monte Carlo (MCMC) methods.

I started working more vigorously on low level image analysis. Then I published two papers in *IEEE Trans. on Pattern Analysis and Machine Intelligence* (Mardia and Hainsworth, 1988; Mardia and Kent, 1988) on image segmentation and spatial classification, respectively. The work with John Kent developed spatial classification using fuzzy membership models. Some of these methods are robust and fast.

Mukhopadhyay: Suppose that a criminal has been on the run for five years. The investigating agencies try to reconstruct a "recent" photo of this criminal based on his file photos which are between five and fifteen years old. The theory and practice behind any such reconstruction fall right in your alley, I am sure.

Mardia: You are absolutely right. Modeling image warping is an area I have worked on. There are many difficult problems here. For example, suppose we have four photos of someone's face at different ages. What kind of image should be called an "average" of these four photos? How different are the four photos from the so-called average image? These are important, interesting and challenging problems. For researchers in machine vision, the problems of identification and tracking are crucial. Success in this area of research depends heavily on one's expertise with the methodologies of spatial statistics, shape analysis and computing.

Mukhopadhyay: I understand that spatial and spatio-temporal modeling are important for environmental monitoring too.

Mardia: Indeed, spatial and spatio-temporal modeling are *essential* for environmental monitoring. For example, what should be the location of the next monitoring station? There is no quick-fix answer for this. Such a question can be addressed with the help of a complex interplay between spatial and spatio-temporal modeling. I had worked with Colin Goodall on some spatio-temporal analysis of multivariate environmental monitoring data (Mardia and Goodall, 1993) and the results were presented at the 1993 Multivariate Conference held at Pennsylvania State University I read related papers at the 1994 Biometric Society meeting in Hamilton, Canada (Goodall and Mardia, 1994) and

in the University of Granada, Spain, in 1996. A discussion paper on the Kriged–Kalman filter was read at the Spanish Statistical and Operations Research Society meeting in November, 1998. This paper marries the two prediction approaches, kriging for space and Kalman filter for time (Mardia, Goodall, Redfern and Alonso, 1998). In July, 1999, a workshop was arranged: Spatial–Temporal Modeling and its Applications in Leeds. In the coming years, I expect a lot of activity in these exciting areas.

Mukhopadhyay: Automatic classifiers are used in harvesting and packaging. A robot does the work, but what can you say about the behind the scene modeling which creates the “brain?”

Mardia: In automatic harvesting of mushrooms, for example, how does one design a robot which will pick only the good mushrooms of a certain size? The problem may appear very simple on the surface, but the mathematics and the implementation of the model behind the algorithms are both far from trivial. In Mardia, W. Qian, D. Shah and K. de Souza (1997), an appropriate Bayesian methodology was developed. Such techniques have a good future in general.

Mukhopadhyay: Would you mention one or two upcoming papers with important applications?

Mardia: Right now I am writing a paper with Fred Bookstein and another one with John Kent. Both papers have to do with bilateral symmetry. In some individuals, one half of the face does not look the same as the other half because one half of the face is distorted. This phenomenon is called hemifacial microsomia and can be corrected only by surgery. We are collaborating with a surgeon, Jim Moss, and a physicist, Alf Linney, at University College, London. The common practice is to take laser scans of the face both before and after the surgery. But how should one go about comparing the before-and-after pictures of the face? How should one compare the images of two brains, one normal and another schizophrenic? This is not a routine matter. Many scientists from different fields are working on these types of problems. Some of my recent work with Fred and John falls in this area.

Mukhopadhyay: How do you get ideas? How do you know which ideas to pursue?

Mardia: Most of my ideas are data driven. Somebody may give me a set of data or it may come out of our consultancy or collaboration. I enjoy looking at data inside out and try to understand the hidden message it has for me. The data gives clues in every turn, but I have to discover the punch line. I remember the fun I used to have when solving different puzzles as



FIG. 14. *Launching of CoMIR. Seated from right to left Three Founding Directors, Kanti Mardia, Mike Smith, David Hogg. Elizabeth Berry (seated between Smith and Hogg) is an additional new Director since 1998.*

a small child. I assume that the data is challenging me to uncover its message, and then it becomes a lot of fun. But in such exercises, I often find that I need newer and sharper tools to proceed. This leads to deeper data analysis and more methodological research. My ideas have been predominantly driven by some kind of data and my attempts to make sense of this data. The bottom line is the challenging data analysis where my research ideas germinate.

CENTER OF MEDICAL IMAGING RESEARCH (CoMIR)

Mukhopadhyay: You are a founding director and now Director of the Center of Medical Imaging Research (CoMIR) in Leeds. The creation of this prestigious center within the university has become a benchmark in your career. Where would you like to start?

Mardia: Within our department, collaborative activities and research in imaging, especially for medical diagnostics, kept growing tremendously through the 1980s. Obviously there was real need for this type of fundamental research in this area. In 1992, three departments in Leeds got together for a joint venture with myself as the founding director. Professor David Hogg, an expert in artificial intelligence from the Department of Computer Science, joined hands. Professor Mike Smith, Director of the Research School in Medicine and Head of the Department of Medical Physics, joined the team. Three of us got together. The University of Leeds pumped in a lot of money and we got some external grants too. The key idea was to bring the three groups of researchers together to solve practical and important problems in medical imaging with clinical imports from the university hospital and other nearby hospitals. The area of research problems may

arise from the interface of medicine, physics, imaging, modeling, design, computer hardware and/or software and so on. The CoMIR has been extremely successful.

Mukhopadhyay: Would you please describe briefly an ongoing CoMIR project?

Mardia: One substantial project consists of longitudinal data collected by an orthopedic surgeon, Professor Bob Dickson, on spinal scoliosis for a cohort of one thousand children in the age group 9–14 years over a period of five years. Images of the spinal columns viewed from two important orthogonal directions have been recorded for these children. The challenge is to be able to forecast the onset of a debilitating disease, spinal scoliosis, as early as practically possible. One has to pinpoint the presence (or absence) of the disease with a very high accuracy. The criteria for recommending the presence (or absence) of the disease have to be formulated, implemented and tested medically. Assuming that everything goes as planned, in the end, the large group of health providers in the clinics have to be trained so that they can diagnose and treat the disease appropriately. Every aspect of this project's successful completion depends heavily on each teamplayer's full participation.

Mukhopadhyay: The project sounds very challenging. Where are you now in this project?

Mardia: The criteria to quantify the curvature of the spinal column are being developed. Alistair Walder and I have developed some of these criteria. The medical trials are continuing to test both the feasibility and validity of the suggested statistical and physical models for the early detection of the onset of spinal scoliosis. Significant theoretical as well as methodological research in statistics would have major impact on children's health. This is the kind of project of national importance for which one needs a center to attract experts from many areas under one roof. The CoMIR has been doing some fundamental work in this area [Mardia et al. (1999)].

Mukhopadhyay: Would you be willing to describe another significant project under CoMIR?

Mardia: The CoMIR has been working on another project of immense practical importance. Many companies manufacture models of parts of a human body, for example, the head, brain, knee and so on, which are used to guide and/or train in the preparation for surgery or as prosthesis for a patient. Jointly with the Department of Anatomy, we are working on a project to develop statistical and computational methods to check the accuracy of the manufactured models.

Consider, for example, a manufactured model of a human head. How is it created in the first place? From a cadaver, the head is surgically removed. Then its internal and external shape, structure and content are thoroughly scanned. This scanned data is then used to create a physical model by stereolithography for a human head. But how should one compare a model head with the original cadaver head? Many deep statistical, mathematical and computational problems are involved in this project. The dental surgeon and anatomist, Alan Jackson, as well as a plastic surgeon, Hiroshi Nisikawa, are participating in all aspects of modeling because ultimately one has to decide how the bones are distributed both around and inside the physical model in relation to the real head. The challenges are numerous. There are no quick or easy solutions. But, at every turn, the team members are making progress. This research at the CoMIR is supported by the Wellcome Trust.

VISITING OTHER PLACES

Mukhopadhyay: Please comment on some of the exciting places you have visited.

Mardia: All my visits have been exciting. Let me, however, comment briefly on some of the visits to the U.S.A., the U.S.S.R., India and Spain. In America, I have visited many places, but visiting Princeton never fails to fascinate me. The environment in Princeton stimulated my research every time I went there. It was so kind of Geoff Watson to invite me for a month every year until 1993. I recall that it started in 1985. I had the opportunity to talk to Geoff and his colleagues at any time during these visits, but the best part of the arrangement had to do with my total freedom whenever I was there. There was never any push to work with so and so or to guide me to think like so and so. I felt totally free to pursue any research project that I wanted to pursue and Geoff was always there to give the moral support and advice. I considered Princeton my second home.

I came to know Colin Goodall at Princeton. A series of collaborations took place and are still continuing between Colin and me over many years. Subsequently, he moved to Penn State. In Princeton, Colin and Geoff organized many workshops on shapes and every single one of these was productive and stimulating. One time I complained to Henry Daniel that I normally got very little money from Leeds to attend these workshops and that I had to spend a large amount of money from my own pocket to take care of the expenses during each trip. Henry said, "Kanti, remember this. It is worth

getting out of England for one whole month every year even if you finance the trips yourself.” (Laughter.)

Mukhopadhyay: (Laughter.) It sounds like very saintly advice!

Mardia: Saintly advice indeed! Lengthy visits to Princeton have slowly been replaced by regular visits to Ann Arbor, Michigan, for collaborations with Fred Bookstein. You may think of it as a transition from Princeton to Ann Arbor. I like visiting Ann Arbor very much. I also visited Penn State a number of times to collaborate with Colin Goodall.

Mukhopadhyay: Didn't you visit Bloomington, Indiana, for some time?

Mardia: In 1977, I came to visit Bloomington, Indiana, for a semester on account of Madan Puri's invitation. I taught two courses and I got the opportunity to work with Madan Puri.

Mukhopadhyay: Any recollections from your trip to the U.S.S.R?

Mardia: In 1976, there was a conference, Stochastic Geometry and Directional Statistics, in Yerevan, Armenia, U.S.S.R., which was attended by a selected group of British delegates. The list of delegates included David Kendall, Brian Ripley, John Kent, Peter Jupp and me. When we arrived there, this woman (an interpreter) repeatedly asked me, “How could you be a British delegate?” You see, I looked so different from other British delegates! Eventually I replied, “Well, I am the contradiction.” (Laughter.)

I think that M. Abramowitz was one of the main organizers. This was a wonderful conference and we were treated like royalty. All the facilities were there and the talks were very enjoyable too. I still remember that the hospitality was remarkable.

We used to get breakfast a little late. It used to be sort of a brunch. I am a pucca (that is, one-hundred percent) vegetarian. The local hostess knew this. So she used to put large amounts of cereal, fruits, bread, salad, etc. on my plate in order to make up for all the missed meat and fish. Everyone else used to get very small portions!

Mukhopadhyay: I believe that there is a punch line to this story. (Laughs.)

Mardia: Oh yes! Then came the conference dinner where each delegate was supposed to propose a toast. When my turn came, I got up and said, “The nice lady who has been looking after me did such a fantastic job. I am so grateful to her. But, I did not quite understand why I was given three or four times the normal portion of bread, fruits and salads during each meal.” My hostess did not realize what I was saying and in the meantime she served me a large fruit plate with a lot of

varieties. It was the largest fruit plate I had ever seen. It was so funny! Everyone broke into laughter. But, as soon as she realized what I had said, she replied calmly through the interpreter, “A cow must eat a lot of grass to sustain good health.” What a defense! I was amazed by her spontaneity and sense of humor. It was hilarious.

Mukhopadhyay: Kanti, you have lived outside of India for nearly thirty-five years. Even though you have Indian roots and heritage, my guess is that many a time you have made trips to India as any other visiting scientist. Any recollections of your special visits to India?

Mardia: Right after I had settled in the United Kingdom, whenever I used to visit India, I made special efforts to go and visit the University of Bombay and give seminars there. This is the place where I grew up as an academic. I have always felt that bond. I was humbled to be invited for the M. C. Chakrabarti Memorial Lectureship Endowment in 1991. There I gave a series of seminars in shape analysis with applications to image processing. When I developed those lecture notes, my shape analysis book was slowly taking its shape. I was also moved and humbled by the presence of my own professor, Mr. Mehta, in the audience. It felt like a fairy tale to me.

After C. G. Khatri's untimely death, a conference in Delhi, organized in 1990, was dedicated to his memory. I felt touched when I was invited to present a paper there in memory of my long-time friend and collaborator. I read the paper on “Khatri's contribution to the matrix von Mises–Fisher distribution and its relation with shape analysis” and I genuinely felt honored.

I have visited Jaipur, India, where my career started and gave some talks in the Department of Statistics. It was wonderful to see again my advisor, Professor G. C. Patni, after many years.

Mukhopadhyay: Did you happen to see Professor B. D. Tikkiwal again?

Mardia: I have seen Professor Tikkiwal in large conferences, for example, at the Indian Science Congress. I do not necessarily go to visit with him when I am in India. He continues to do research on sampling. He also came to visit England and I invited him to come to Leeds, probably in 1980. He was passing through but we had some nice times together.

Mukhopadhyay: Are you going to mention your trips to Spain?

Mardia: I recall visits to the Department of Statistics in the University of Granada, Spain, for joint projects on distribution theory and spatio-temporal modeling

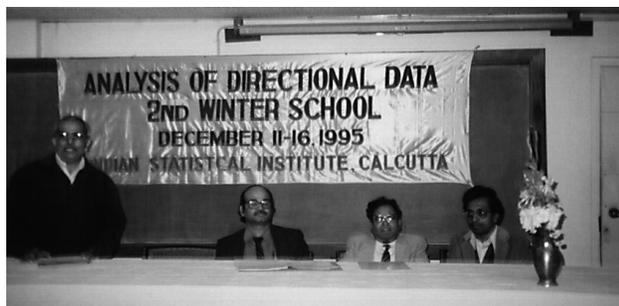


FIG. 15. Conference at the Indian Statistical Institute, Calcutta, 1995. From left to right: C. H. Sastri (Head, Applied Statistics Division), S. B. Rao (Director), K. Mardia and A. SenGupta.

during the last four years. I have actively collaborated with Ramon Gurtziat and José Angulo. Either I visit there once a year or someone from there visits Leeds. José visited Leeds in July, 1999.

However, the visits to the Continent do not exactly suit us since we are completely vegetarians. Even in salads, one will often find the crunchies prepared with ham! But, lately when we have visited, we have rented an apartment with kitchen facilities.

Mukhopadhyay: During a recent visit to India, you have launched long-term joint collaborations with scientists from the Indian Statistical Institute (ISI), Calcutta. Would you like to mention that?

Mardia: At one point, the Indian High Commissioner to the United Kingdom, Dr. L. M. Singhvi, became the Ambassador from India to the United Kingdom. He was very keen on creating interactions among the universities in the United Kingdom and India. He suggested looking into possible collaborations and exchange programs between Leeds and some Indian universities. I thought that ISI, Calcutta, was the right place to begin this exchange program on an experimental basis because the activities in image analysis and machine vision were strong in both places. I approached Professor Jayanta Ghosh and we made formal arrangements in 1995 to embark on the program in the next five years. The progress has been slow but several things have happened. A large conference was held in 1998–99 in ISI, Calcutta, where Ian Dryden gave a workshop, Shapes and Images. In the conference, I happened to deliver both the keynote and closing addresses. These were attended by groups of researchers in machine vision, pattern recognition, statistics, mathematics, computer science, both from within ISI, and other academic institutions as well as companies and industries. There were participants from overseas too. This was a very high profile event.

At the end of the conference, there was substantial dialogue among various groups and this was one of the objectives for initiating such a large exchange program in the first place. The former Director of ISI, Professor S. B. Rao, mentioned that this was the first time the statisticians and the staff members from the computer vision and image analysis within ISI got together on a large scale. I anticipate that there will be a reciprocal conference on shapes and images in Leeds in the year 2000 to preserve the flame. I expect a delegation of three to six researchers from India to Leeds in that event.

COLLABORATORS, COLLEAGUES AND PERSONALITIES

Mukhopadhyay: Let us now hear about some influential collaborators, colleagues and personalities.

Mardia: Let me start with Geoff Watson. I first met Geoff in February or March, 1977, in Houston, Texas. The way I met him was very interesting. Earlier, Tom Downs visited us in the United Kingdom and I went to Houston to reciprocate that visit. I heard that Geoff was coming to Houston as an external examiner of one of Tom's Ph.D. students. Geoff was to stay in the university guest house. He was possibly returning from a skiing trip. He missed some connecting flights on account of bad weather and his plane was very late. He was very tired but he somehow arrived on campus around 3 a.m. Geoff knocked on the entrance to the guest house a few times, but no one came to open the door for him. He slept through the rest of the night on the "welcome mat" at the entrance.

Next morning, the Ph.D. exam was right on schedule. I was invited to observe the proceedings. Geoff arrived there with a smile on his face. Last night's episode did not bother him even the least bit. He was laughing and joking as he described what had actually happened. This was my first encounter with Geoff. He was probably the most rugged man I ever met.

Later that day, Geoff gave a seminar on genetics, and in the evening we formally met and went out to dinner together with a couple of other people. We had some informal discussions. He spoke very kindly of my book on directional data which he had reviewed earlier. Geoff was of course a pioneer in this area and his encouragement meant a lot to me. Geoff, Tom and I went to a cowboy show and Geoff quickly bought and wore a very distinctive cowboy hat. I did not anticipate this at all. He was very easy to get along with!

Mukhopadhyay: Any other recollections about Geoff Watson?



FIG. 16. Kanti Mardia with Geoff Watson, in Houston, 1977.

Mardia: I first visited Princeton in 1985. Henry Daniel was also visiting at that time and we were living close to each other on the campus of the Institute of Advanced Studies. That period was particularly hard for Geoff. His department was disintegrating. In fact we attended a musical evening, “On the demise of the Department of Statistics” and Henry Daniel took part in the show. Colin Goodall’s wife, Lisa, had a part in this too. It was a great musical evening but the unfortunate part was that we were bidding farewell to Geoff’s department.

Geoff was busy with regular teaching duties. But frequently he appeared very frustrated. He even looked depressed sometimes. So, I used to talk to him about Yoga exercises.

Whenever we saw each other, we discussed what both of us were doing, but we never came up with a problem where the two of us could work together. He was always very modest about his own research. Geoff was also a great painter. He was his own man when he painted. Geoff visited Leeds perhaps four or five times. He last visited Leeds about four years ago. Whenever we came to Princeton, Geoff’s wife, Shirley, was kind to take care of us. They were wonderful hosts.

Mukhopadhyay: You edited *The Art of Statistical Science* (Mardia, 1992a), a seventieth birthday festschrift volume for Geoff Watson. Did you present the volume to him in person?

Mardia: In 1992, Geoff turned seventy and he was to retire. I prepared a special volume of papers in his honor. Many collaborators and admirers of Geoff participated in this volume. All contributors responded enthusiastically. In 1993, there was a conference in Princeton where many of us participated. Michael

Stephens, Jim Durbin and John Kent were also in attendance. One of his daughters is a famous opera singer and she gave a recital. Geoff became very emotional and he had tears in his eyes. At the end of the conference, I presented the festschrift volume to Geoff. He could barely speak and said only a few words of appreciation. After I presented the festschrift volume, he presented to me one of his many beautiful paintings in water colors.

Mukhopadhyay: When did you last see Geoff Watson?

Mardia: Geoff was visiting Colin Goodall in New Jersey. This was 1997 when Pavan and I drove there to say hello to him. At that time he was creating a painting of the Fine Hall. He kindly gave me a print of that painting.

Mukhopadhyay: Who comes to your mind next?

Mardia: Let me give you some recollections about David Kendall. I came to know David more than twenty years ago when he invited me to Cambridge to give a seminar on directional data. My colleague John Kent was one of David’s students.

From the very beginning, David and I liked each other. Subsequently, we exchanged ideas on stochastic geometry. I got to know him well during our trip to Yerevan, Armenia, U.S.S.R., on a delegation. A lot of people casually think that directional data is just another part of multivariate analysis. In Russia, when we walked together, David would emphasize that we must convince the mathematicians and statisticians that such a simplistic attitude is not correct. He argued vigorously that non-Euclidean geometry and topology actually set apart directional data and shape analysis from traditional multivariate analysis. He discussed these with unmistakable energy.

He knew my hobby of collecting editions of the *Rubaiyat of Omar Khayyam*. One day, David mentioned that he was once invited to the Omar Khayyam Club in London during a special event. He said that most of the major publishers were represented there. He went on to describe how this club was unique in its mission. At that time I did not know anything about this club. Eventually I found the club and now I am a member of the Omar Khayyam Club. It is quite a merry place. Sometimes visitors give light-hearted and hilarious lectures on Omar Khayyam and Edward FitzGerald, and other times the gathering may be quite formal. The membership consists of people from all walks of life. I presented my millennium paper (Mardia, 2000) entitled “Omar Khayyam, René Descartes and solutions to algebraic equations” and put forward



FIG. 17. *Kanti Mardia with David Cox in Oslo, 1977.*

a thesis that Omar Khayyam's work during the twelfth century might have foreshadowed the contributions of Descartes in analytical geometry.

Mukhopadhyay: You mentioned Fred Bookstein before. Do you wish to add anything else?

Mardia: The proceedings volume of the first conference on shape, organized in Leeds in 1995, was dedicated to Fred Bookstein and David Kendall. They are both pioneers in this field. I may say that Fred complemented David's fundamental ideas and vision in his own characteristic style and created the impetus for this field's phenomenal growth.

Fred is superb in giving intuitive geometrical arguments. Frequently we have to work hard to come up with algebraic validation of Fred's original "simple" claims. But sometimes Fred's intuitive answer and the algebraically derived answer will differ slightly, especially in higher manifolds. Then, the situation becomes serious! (Laughs.)

Mukhopadhyay: Do you now wish to give some remarks about D. R. Cox?

Mardia: With great pleasure. Let me start by saying that David R. Cox got his Ph.D. degree in statistics from the University of Leeds in 1949. He is the "jewel in the crown" of Leeds. David was jointly supervised by Henry Daniel from the Wool Industries Research Association (WIRA) and Barnard Welch from the university. Some of the early works of David Cox had to do with fiber and yarn data having long-range and serial correlations.

I first met David a long time ago, perhaps when I was in Newcastle. David is very easy to get along with and talk to for his comments and advice. When he was in London, I used to visit him for his advice and guidance on technical as well as administrative matters. When I work on some new results, I ask him for advice or related references. Regardless of the problem, whether it is statistical, mathematical,



FIG. 18. *Visit to Omar Khayyam Tomb in Nishapur, Iran, 1994. Standing in the garden alongside Omar Khayyam statue.*



FIG. 19. *Kanti Mardia with Ulf Grenander, in Newton Institute, Cambridge, 1994.*

conceptual- or administrative in nature, David always has something very valuable to say.

Now he is in Oxford and he is technically retired. But we all understand that retirement for David R. Cox means that he is a full-time researcher. He is a very popular person and a great, inspiring speaker. He is always in demand as an invited speaker all over the world.

Mukhopadhyay: So far you have not mentioned Ulf Grenander or Stu Geman of Brown University.

Mardia: In 1985 or 1986, there was a workshop or conference in Edinburgh where I first met Ulf Grenander and Stu Geman. Subsequently, I have visited Brown a number of times. I have become close to their group. I find Stu Geman extremely clever and we get along very well. When we discuss topics in image analysis, he will freely share new ideas with me. Often these ideas, once polished and tightened, lead to new concepts or measures.

Ulf Grenander came to Leeds as an invited participant at a conference, “The Art and Science of Bayesian Image Analysis, in 1997. Of course, Ulf is mathematically very deep. Ulf is always very precise in what he says. By talking to him, one will easily discover that he is a great mathematician. At the Newton Institute in Cambridge there is a regular program of workshops and symposia to bring experts together. I have taken part in some of these workshops. So I came to know Ulf and his wife, Paj, well. I know Paj as a very outgoing person. She is an energetic bridge player. I once asked Ulf, “Your wife plays bridge in her spare time. What do you do in your spare time?” He replied, “I do not have much spare time, but when I do, I do more mathematics.”

Mukhopadhyay: So far, you have talked about some of the leading statisticians. In your research, you have met and worked with many scientists from other fields. Do you wish to mention any of these?

Mardia: I have been fortunate to meet many leading scientists in the areas of machine vision and image analysis. I may mention Joseph Kittler from Surrey and David Hogg, my colleague in the Department of Computer Science in Leeds. From the United States, I may mention some of the pioneers such as Azriel Rosenfeld and Laveen Kanal, both from the University of Maryland, and Anil Jain from Michigan State University, East Lansing. These are some of the top people in what they do.

LOGIC, STATISTICS AND JAIN RELIGION

Mukhopadhyay: Over the years you have done research and written extensively on the science and logical structure of the Jain religion. What is the origin of this aspect of your life?

Mardia: Sirohi is my birthplace where the predominance of Jain religion and culture is the way of life. I was nourished by the practices and philosophy of Jainism. My life has since been greatly influenced by this environment. The Jains are pure vegetarians which implies the total exclusion of meat, fish, eggs and even

onions and potatoes from their diet. My involvement and passion for the Jain religion has given me a lot of excitement in life. A part of it is because I was brought up within the Jain tradition.

Mukhopadhyay: In your Inaugural Lecture delivered at Leeds in October 1975, you had talked on “Do-it-yourself statistical analysis.” This lecture was a serious mix of science, philosophy, logic, statistics and Jainism (Mardia, 1976).

Mardia: In Leeds up to 1980s, when one received the position of a full professor, huge official ceremonies were held for the inauguration. This was a big moment in anyone’s life. The Professor would deliver a substantial inaugural address directed toward the colleagues as well as the larger community. It is an overwhelming experience. I got the Chair in Leeds in 1973, and on 13 October, 1975, I delivered the inaugural address. Lord Boyle was Vice-Chancellor of Leeds then.

In a scientific theory, one proves many results under some basic assumptions or hypothesis. In statistics, we make inferences regarding a population with the help of the information gained from a random sample. This is inductive logic. But, no assumption or hypothesis is perhaps universally true or false. In statistics, we say, “Do not reject the null hypothesis,” but is it equivalent to say, “Accept the null hypothesis?” In statistics, there is a middle ground which is because in the logic of statistics, there is no place for absolutism. Simply put, a core in Jainism says, “It is wrong to assert absolutely.” In fact, I really should say, “Maybe it is wrong to assert absolutely.”

The idea of *nonabsolutism*, a principle which is shared by the conditional predication, was advocated by Karl Popper, one of the greatest logicians of the twentieth century. J. B. S. Haldane, a famous geneticist and statistician, also hailed nonabsolutism. My Inaugural Lecture (Mardia, 1976) outlined the arguments which thread together science, philosophy, logic, statistics, Jainism and decision-making. I emphasized the utmost need for solid understanding of statistical logic and principles whenever some useful decisions are to be made. No statistical package will serve one iota of purpose for the overall good of the society unless the user of the statistical package knows both statistics and the package extremely well.

Mukhopadhyay: In your Inaugural Lecture, you pointed out that through the principle of conditional predication, one may try to justify the logical foundation of Jainism. Is there any other viewpoint?

Mardia: One may consider the holistic view called Anekāntvāda. From this viewpoint, the philosophy

of Jainism requires that one must consider anything as a whole in order to understand it. Understanding some bits and pieces about something is not same as understanding the whole thing.

Mukhopadhyay: The connection between what you just said and what we normally do in statistics is very clear. Statisticians take a look at part of a population only, and by examining its features try to guess the features in the whole population. Thus the inferences made cannot be perfect. When I say that, I actually become a believer of nonabsolutism.

Mardia: Your understanding is correct.

Mukhopadhyay: You have written a very authoritative book on Jainism. Do you wish to mention anything on that?

Mardia: Jain religion is not personality based. It derives its foundations from what is called Jain-science. Once I sorted out the logical links and scientific arguments, I discussed my axiomatic theory with some scholars of Jain religion, religious leaders and leading monks both in India and abroad. My theory has been received very well. Subsequently, in 1990, I published a book, *The Scientific Foundation of Jainism*. The book has now gone into a second edition. I went to a Indian publisher in India because then the book would be more affordable to the general public. But, looking back, I realize that it was a mistake. The book is cheaper in India, but the publication quality is not very high and its copies are hardly distributed overseas. The book is essentially for members of the younger generation with scientific minds.

Mukhopadhyay: You authored a booklet, *Jain Thoughts and Prayers* (Mardia, 1992b), which was prepared also for the younger generations.

Mardia: That is correct. We have to get the younger generation involved; my booklet helps in that mission. I may add that a Jain Center, including a temple, has been built in Leicester (England). I was deeply involved with the whole project for a number of years. I am Vice-Chairman of the Yorkshire Jain Foundation, formally established in April, 1987. The Foundation holds a library on Jainism and comparative religions. I am also Vice-Chairman and a Trustee of the Jain Academy which promotes educational initiatives related to Jain Studies.

MANY HOBBIES

Mukhopadhyay: Do you have any hobbies?

Mardia: I started learning chess by myself when I was six years old. During my school and college days,

I played chess extensively. My eldest brother used to play chess. I had a great fascination for this wonderful game. I became quite proficient in this game. As a student representing the University of Bombay, I played in a chess tournament, reached the college-level final, but then I lost in the final round. That loss put a damper on my pursuit of chess! I discovered later that the chap who defeated me in the final actually went on to become the national champion. I already was committed to becoming a statistician! (Laughter.)

I still play chess now and then. Everyone in my family plays chess and I hope that my four-year-old grandson, Ashwin, will pick it up too. Indeed, my grandson plays with me, but at present sometimes he makes up his own rules—he has to win! (Laughter.)

Mukhopadhyay: Do you also play bridge?

Mardia: I play bridge occasionally with my family. In the past, I have also taken part in bridge tournaments in Leeds. I collected some master points, but I was spending too much time on this to continue to play at the tournament level. Subsequently, I gave up playing in tournaments.

Mukhopadhyay: Among colleagues, have you met some exciting chess or bridge players? Do you have other hobbies?

Mardia: I am sure that I have, but I do not remember many details. I can tell you an interesting story. Probably in 1977, when I did lot of traveling from Bloomington, I went to Virginia to give a seminar. Before the seminar, I was talking to Jack Good and casually mentioned that I heard he was very good in chess and I was also interested in chess. He said, “Very good. Let us play a game before your seminar then.” It turned out to be the pre-seminar game. (Laughter.)

He is an extremely good chess player. He made a number of great moves. Even though I gave him a good fight, I naturally lost the game to a much better player.

My other hobby is to collect antiquarian books. When I go to conferences or visit places, whether in Europe, Asia, the U.S.A. or Canada, I must go and check out some of the best local antique bookshops. I watch whether any book fair will coincide with a conference in some city and plan my itinerary accordingly so that I can also go to the book fair while I am in that neighborhood. I have a large library of antiquarian books. When other conference delegates go to visit palaces and museums, Kanti Mardia goes to some out of the way old bookshops! (Laughter.)

In Ann Arbor, I feel at home when I walk around. One reason is that there are quite many exciting

bookshops there for used or old books. I love buying and reading old books on art, religion, culture, music, society, languages, history of computing and travel. Sometimes Shirley, Geoff Watson's wife, took me to book fairs in Princeton.

Mukhopadhyay: How did this hobby get started?

Mardia: I started with the *Rubaiyat of Omar Khayyam*. Over the years, I have gathered a large collection. I mentioned earlier that I am a member of the Omar Khayyam Club in London.

IMMEDIATE FAMILY

Mukhopadhyay: What do you wish to mention about your immediate family?

Mardia: I consider myself very lucky to have Pavan as my wife. Pavan took care of the family's upbringing and practically all other conceivable responsibilities on top of her full-time career as a math school teacher. She is very talented. She sacrificed much more than anyone will ever know. If I am light, she is the electric current; if I am software, she is the hardware. Indeed, she ran the family and kept me in line, which is not always easy. I am actually a good-for-nothing on the domestic front. Perhaps, I should not have said that. (Laughter.)

Pavan is patient and she stays calm when suddenly some unexpected things happen. I am literally the opposite of that. She does not say much, but on the other hand I am too extrovert. Thank God, Pavan's habits and demeanor complement mine. (Laughter.)

She took early retirement about four years ago so that the two of us are now able to travel abroad together. She also takes over my general secretarial work when I travel. On the road, to have someone to talk to or share something exciting is always healthy for both minds and souls. We have many common interests; for example, we both swim, enjoy traveling and collect antiquarian books.

Mukhopadhyay: How about your son, Hemant, and daughters Bela and Neeta? Do they take after you or their mom?

Mardia: From the very beginning my children have been more attached to their mother and that is quite expected. They also inherited the best qualities from Pavan. Generally speaking, they are quite calm and patient. Our children can relate to Pavan easily. I am always there for them, but for everyday's nitty-gritty details, the children will probably have more confidence in their mom. (Laughter.)

Mukhopadhyay: (Laughter.) Kanti, there is no need to explain. I understand exactly where you are coming from. What do your daughters and son do?



FIG. 20. *Mardia's children with spouses, 1991. Standing from left to right: Raghu (Bela's husband), Hemansu (Neeta's husband), Bela (daughter) and Hemant (son). Sitting from left to right, Kanti Mardia, Preeti (Hemant's wife), Neeta (daughter) and Pavan Mardia.*

Mardia: Quite early, Pavan and I decided that our children must have the freedom to pursue their own interests to build careers. We were always available for advice and guidance, but we never pushed the children to any particular profession. Our children are now grown-ups, and I am proud of their individualities and specialties.

Our eldest daughter, Bela, is the only one who took some statistics courses for her degree. She has been working as a systems analyst and her husband, Raghunathan, is a medical doctor. They have given me a grandson, Ashwin, whom I mentioned earlier. Bela lives in Hull with her family.

Our son, Hemant, studied electrical engineering. He is now the director of a company in telecommunications that manufactures special types of low-frequency filters for digital technology. His wife, Preeti, is a food scientist and is now a manager of marketing. Hemant and Preeti live near our place.

Our youngest daughter, Neeta, lives more than two hundred miles away. She is a lawyer and her husband, Hemansu, is a purchasing manager in a large business complex. Raghu, Hemansu and Preeti hail, respectively, from Southern India, Gujarat and Delhi. A good cross-section of India is thus represented in my immediate family.

Mukhopadhyay: Do you get to see your children and their families frequently?

Mardia: We are very close to one another. We visit them or they come to visit us on birthdays, holidays, and other special occasions. So we all constantly keep in touch.

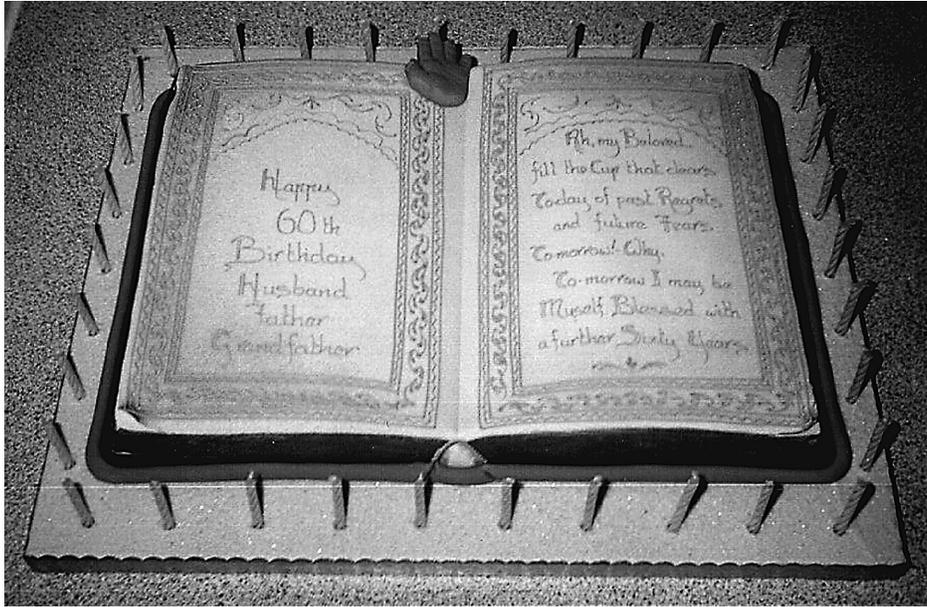


FIG. 21. Kanti Mardia's sixtieth birthday celebration in 1995. The birthday cake with Omar Khayyam's Rubai.

My children gave me a surprise sixtieth birthday party. Many of my friends from Newcastle and Hull were invited. Leeds was very well represented too. It was a big affair and the party was arranged in a cunning way! I had no idea what was about to hit me!

Mukhopadhyay: You just said you were close to your children. So what happened! (Laughter.)

Mardia: I thought all along that I knew my wife, the children, and my friend Raj very well! Behind my back, they were in this together. (Laughter.)

On a serious note, I add that I was moved and I was delighted to see so many friends and well-wishers. I enjoyed the party thoroughly.

RETIREMENT 2000

Mukhopadhyay: I hear that you are to retire in September, 2000. That is going to be an important landmark, in your career. In the professional life, are you resetting the priorities?

Mardia: Retirement is mandatory at age 65 in U.K. universities. But because I am still active in research and I have several grants, I was to become at least an emeritus professor after retirement. I have started thinking about the changes the retirement will bring. Long-term prospects are totally unknown. Things will no doubt be different. I will probably have a small desk in the corner of an office somewhere. (Laughs.)

On a serious note, I have been appointed as a full-time Senior Research Professor from 1 October, 2000,

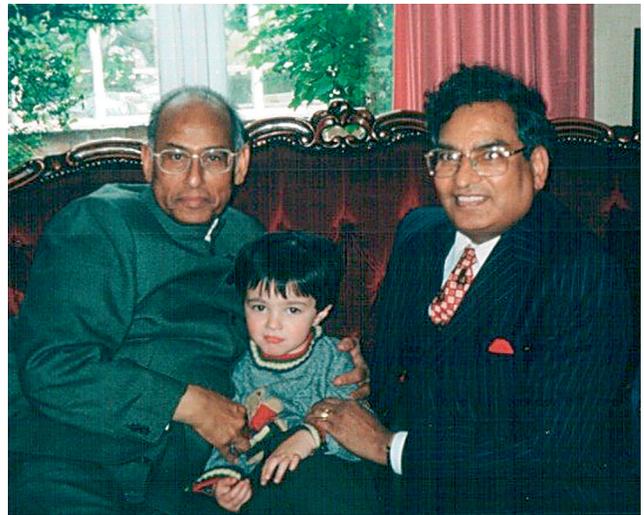


FIG. 22. Kanti Mardia with his grandson, Ashwin, and the Indian High Commissioner, Dr. L. M. Singhvi, in Leeds, 1996.

at Leeds—a special position of its type created for me. So things are going to be quite exciting.

Mukhopadhyay: Congratulations. This sounds like a great opportunity and you certainly deserve it. But let me ask you this. You have been the mover and shaker at the University of Leeds for a long time. What are some of the items on your “must do list” before retirement?

Mardia: Upon my retirement from the University of Leeds on September 30, 2000, I want to finish so many things! My top priority is to finish the book on spatial analysis with John Kent. Another top priority for me

is to prepare the department in a way that in the next Research Assessment Exercise, due 2001, we receive the top grade. I want the department to march forward with solid footing. My successor will have to come aboard, along with a few other important appointments, so that the new leadership and other appointees may overlap with my administration for about a year. This is to make sure that the transition is as smooth as possible and none of the ongoing projects are affected adversely. This is a very difficult task to accomplish. I have prepared the department for the new leadership as best as I possibly can.

Mukhopadhyay: What will you be doing immediately after retirement from Leeds?

Mardia: I will be collaborating with the researchers at the Center of Medical Imaging Research (CoMIR) in Leeds. In the newly created position of Senior Research Professor, I will be stationed at the University of Leeds. Several universities in the United Kingdom have urged me to join their faculty as a research professor and accordingly I may visit these places perhaps a couple of times in order to stimulate their research programs. I will continue to visit abroad as I have done for a number of years.

Mukhopadhyay: For the post-retirement life, in the long haul, have you made any plans?

Mardia: Statistical research has always fascinated me and I have greatly enjoyed doing whatever I have done. If my wife's and my health cooperate, I will continue remaining active in research. Changes in our lives and careers are on the horizon, and naturally we wait with some apprehensions. But we have weathered changes in our lives so many times in the past forty years or so! Hopefully, this time around we will do all right too. I remain very optimistic.

Mukhopadhyay: You have several research grants right now. I suppose that some of these grants will continue into your retirement.

Mardia: This is right. I am all set for a number of years. A few postdoctoral fellows and four graduate students will continue to work with me. However, the Senior Research Professorship will allow additional postdoctoral fellows and graduate students.

The remit of this position is to continue to promote and lead research in the department. We already have made plans for the next five years' LASR workshops. My guess is that the research papers will flow for many years to come. A joint paper with Chris Glasbey is expected to be read to the Royal Statistical Society in the near future, I think.

I hope to continue my collaborations on projects at the CoMIR. I hope something big and something useful will evolve from the joint initiatives between Leeds and the Indian Statistical Institute. I would like to visit the United States perhaps for two or three months a year to carry out joint research with my collaborators.

Naturally, there will be some financial constraints, but we will be all right as long as I stop spending money on those antiquarian books! (Laughs.)

Mukhopadhyay: Do you want to mention any other big plans?

Mardia: I have decided that I am not going to start the revisions of any of my earlier books. However, I may not mind an advisory role in revising the multivariate analysis book. I will not really enjoy rehashing these old materials. I have decided to take up the challenge to write two books simultaneously. I expect that one of the books will be on spatio-temporal modeling. The other one will likely be on statistics of images. I organized a number of conferences and edited special volumes in related areas. The material is there. But, the books are expected to be more self-sufficient and comprehensive. A synthesis would be the most important aspect in each book. These are two very substantial future projects. Hopefully I will succeed.

I am also seriously looking into the history of computing. I may narrow this field down to the history of statistical computing. We all know and appreciate the fact that the area of statistical computing has come a long way in the past fifty or sixty years. It will be great to compile this history of development.

I have so many serious projects planned beyond retirement! I sometimes wonder myself whether I will be able to reach my goals. An Indian proverb comes to mind: "When I had teeth, I could not afford those crispy chickpeas. But now that I can afford an unlimited supply of crispy chickpeas, to my amazement I discover that I have no teeth left." (Laughter.)

Mukhopadhyay: Your record speaks for itself. I have all the confidence that you will indeed finish all these marvelous projects in the very near future. Thank you so much for this conversation which I have enjoyed immensely. I wish you, Pavan, and your loved ones all the health and happiness in the world.

Mardia: Many thanks, Nitis.

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REFERENCES

- ANDERSON, T. W. (1958). *Introduction to Multivariate Statistical Analysis*. Wiley, New York.
- BESAG, J. E. (1986). On the statistical analysis of dirty pictures (with discussion). *J. Roy. Statist. Soc. Ser. B* **48** 259–302.
- BINGHAM, C. and MARDIA, K. V. (1978). A small circle distribution on a sphere. *Biometrika* **65** 379–389.
- BOOKSTEIN, F. L. (1986). Size and shape spaces for landmark data in two dimensions (with discussion). *Statist. Sci.* **1** 181–242.
- BOOKSTEIN, F. L. (1989). Partial warps: thin plate splines and the decomposition of deformations. *IEEE Trans. Pattern Anal. Machine Intelligence* **11** 567–585.
- BOOKSTEIN, F. L. (1996). Landmark methods for forms with landmarks: morphometrics of group differences in outline shape. *Medical Image Analysis* **1** 225–243.
- COCHRAN, W. G. and COX, G. M. (1950). *Experimental Designs*. Wiley, New York.
- CRAMÉR, H. (1946). *Mathematical Methods of Statistics*. Princeton Univ. Press.
- DRYDEN, I. L. and MARDIA, K. V. (1989). Shape distributions for landmark data. *Adv. Appl. Probab.* **21** 742–755.
- DRYDEN, I. L. and MARDIA, K. V. (1991). General shape distributions in a plane. *Adv. Appl. Probab.* **23** 259–276.
- DRYDEN, I. L. and MARDIA, K. V. (1998). *Statistical Shape Analysis*. Wiley, New York.
- FISHER, N. I., LEWIS, T. and EMBLETON, B. J. J. (1987). *Statistical Analysis of Spherical Data*. Cambridge Univ. Press.
- FISHER, R. A. (1953). Dispersion on a sphere. *Proc. Roy. Soc. London Ser. A* **217** 295–305.
- GEMAN, S. and GEMAN, D. (1984). Stochastic relaxation, Gibbs distributions and the Bayesian restoration of images. *IEEE Trans. Pattern Anal. Machine Intelligence* **6** 721–741.
- GOODALL, C. R. and MARDIA, K. V. (1994). Challenges in multivariate spatio-temporal modelling. In *Proceedings XVII International Biometrika Conference* **1** 1–17. Hamilton, Canada.
- GOODALL, C. R. and MARDIA, K. V. (1999). Projective shape analysis. *J. Comput. Graph. Statist.* **8** 143–168.
- GOWER, J. (1975). Generalized Procrustes analysis. *Psychometrika* **40** 33–51.
- HARTLEY, H. O. (1950). The use of range in analysis of variance. *Biometrika* **37** 271–280.
- HARTLEY, H. O. and SMITH, W. B. (1968). A note on the correlation of ranges in correlated normal samples. *Biometrika* **55** 595–597.
- JOHNSON, N. L. and KOTZ, S. (1972). *Continuous Multivariate Distributions*. Wiley, New York.
- JUPP, P. E. and MARDIA, K. V. (1979). Maximum likelihood estimators for the matrix von Mises–Fisher and Bingham distributions. *Ann. Statist.* **7** 599–606.
- KEMPTHORNE, O. (1952). *The Design and Analysis of Experiments*. Wiley, New York.
- KENDALL, D. G. (1989). A survey of the statistical theory of shape (with discussion). *Statist. Sci.* **4** 87–120.
- MARDIA, K. V. (1962). Multivariate Pareto distributions. *Ann. Math. Statist.* **33** 1008–1015.
- MARDIA, K. V. (1967a). Some contributions to contingency-type bivariate distributions. *Biometrika* **54** 235–249.
- MARDIA, K. V. (1967b). Correlation of the ranges of correlated samples. *Biometrika* **54** 529–539.
- MARDIA, K. V. (1967c). A nonparametric test for the bivariate two-sample location problem. *J. Roy. Statist. Soc. Ser. B* **29** 320–342.
- MARDIA, K. V. (1967d). Discussion of “A study of low-temperature probabilities in the context of an industrial problem,” by V. D. Barnett and T. Lewis. *J. Roy. Statist. Soc. Ser. A* **130** 202.
- MARDIA, K. V. (1968). Small sample power of a nonparametric test for the bivariate two-sample location problem in the normal case. *J. Roy. Statist. Soc. Ser. B* **30** 83–92.
- MARDIA, K. V. (1970a). *Families of Bivariate Distributions*. Griffin, London.
- MARDIA, K. V. (1970b). Measures of multivariate skewness and kurtosis with applications. *Biometrika* **57** 519–530.
- MARDIA, K. V. (1971). The effect of nonnormality on some multivariate tests and robustness to nonnormality in the linear model. *Biometrika* **58** 105–121.
- MARDIA, K. V. (1972). *Statistics of Directional Data*. Academic Press, New York.
- MARDIA, K. V. (1975). Statistics of directional data (with discussion). *J. Roy. Statist. Soc. Ser. B* **37** 349–393.
- MARDIA, K. V. (1976). Do-it-yourself statistical analysis. Inaugural address. *Leeds Review* **19** 79–98.
- MARDIA, K. V. (1977). Mahalanobis distances and angles. In *Multivariate Analysis IV* (P. R. Krishnaiah, ed.) 495–511. North-Holland, Amsterdam.
- MARDIA, K. V. (1989). Discussion of “A survey of the statistical theory of shape,” by D. G. Kendall. *Statist. Sci.* **4** 108–111.
- MARDIA, K. V. (1990). *The Scientific Foundation of Jainism*. Motilal Banarsidass, Delhi.
- MARDIA, K. V. (1991). On longevity and life-line. *J. Appl. Statist.* **17** 443–448.
- MARDIA, K. V., ed. (1992a). *The Art of Statistical Science. A Tribute to G. S. Watson*. Wiley, New York.
- MARDIA, K. V. (1992b). *Jain Thoughts and Prayers*. Yorkshire Jain Foundation, Leeds.
- MARDIA, K. V. (2000). Omar Khayyam, René Descartes and solutions to algebraic equations (abstract). *International Congress in Commemorating Hakim Omar Khayyam Neyshabouri, 900th Death Anniversary* 9. Neyshabour, Iran.
- MARDIA, K. V., BACZKOWSKI, A. J., FENG, X. and HAINSWORTH, T. J. (1997). Statistical methods for automatic interpretation of digitally scanned fingerprints. In *Special Issue: Pattern Recognition Letters* (E. S. Gelsema and L. N. Kanal, eds.) **18** 1197–1203. North-Holland, Amsterdam.
- MARDIA, K. V. and CONSTABLE, P. D. L. (1992). On shape and size analysis of palmar interdigital areas. *J. Appl. Statist.* **19** 285–292.
- MARDIA, K. V. and DRYDEN, I. L. (1989). The Statistical analysis of shape data. *Biometrika* **76** 271–281.
- MARDIA, K. V. and EDWARDS, R. (1982). Weighted distributions and rotating caps. *Biometrika* **69** 323–330.

- MARDIA, K. V. and GADSEN, R. J. (1977). A circle of best-fit for spherical data and areas of vulcanism. *J. Roy. Statist. Soc. Ser. C* **26** 238–245.
- MARDIA, K. V. and GOODALL, C. R. (1993). Spatial temporal analysis of multivariate environmental monitoring data. In *Multivariate Environmental Statistics* (G. P. Patil and C. R. Rao, eds.) 347–386. North-Holland, Amsterdam.
- MARDIA, K. V., GOODALL, C. R., REDFERN, E. J. and ALONSO, F. J. (1998). The Kriged Kalman filter (with discussion). *Test* **7** 217–285.
- MARDIA, K. V., GOODALL, C. R. and WALDER, A. N. (1996). Distributions of projective invariants and model-based machine vision. *Adv. Appl. Probab.* **28** 641–661.
- MARDIA, K. V. and HAINSWORTH, T. J. (1988). A spatial thresholding method for image segmentation. *IEEE Trans. Pattern Anal. Machine Intelligence* **10** 919–927.
- MARDIA, K. V. and HOLMES, D. (1980). A statistical analysis of megalithic data under elliptic pattern. *J. Roy. Statist. Soc. Ser. A* **143** 293–302.
- MARDIA, K. V. and JUPP, P. E. (1999). *Statistics of Directional Data*, 2nd ed. Wiley, New York.
- MARDIA, K. V. and KENT, J. T. (1988). Spatial classification using fuzzy membership models. *IEEE Trans. Pattern Anal. Machine Intelligence* **10** 659–671.
- MARDIA, K. V., KENT, J. T. and BIBBY, J. M. (1979). *Multivariate Analysis*. Academic Press, New York.
- MARDIA, K. V., KENT, J. T. and BRIDEN, J. C. (1983). Linear and planar structure in ordered multivariate data as applied to progressive demagnetization. *Geophys. J. Roy. Astron. Soc.* **75** 593–621.
- MARDIA, K. V. and MARSHALL, R. J. (1984). Maximum likelihood estimation of models for residual covariance in spatial regression. *Biometrika* **71** 135–146.
- MARDIA, K. V. and PURI, M. L. (1978). A spherical correlation coefficient robust against scale. *Biometrika* **65** 391–395.
- MARDIA, K. V., PURI, M. L. and EDWARDS, R. (1978). Analysis of central place theory. *Bulletin of the International Statistical Institute* **47** 93–110.
- MARDIA, K. V., QIAN, W., SHAH, D. and DE SOUZA, K. (1997). Deformable template recognition of multiple occluded objects. *IEEE Trans. Pattern Anal. Machine Intelligence* **19** 1036–1042.
- MARDIA, K. V. and SPURR, B. D. (1973). Multisample tests for multimodal and axial circular populations. *J. Roy. Statist. Soc. Ser. B* **35** 422–436.
- MARDIA, K. V. and SUTTON, T. W. (1975). On the modes of a mixture of two von Mises distributions. *Biometrika* **62** 699–701.
- MARDIA, K. V. and SUTTON, T. W. (1978). A model for cylindrical variables with applications. *J. Roy. Statist. Soc. Ser. B* **40** 229–233.
- MARDIA, K. V., WALDER, A. N., BERRY, E., SHARPLES, D., MILNER, P. A. and DICKSON, R. A. (1999). Assessing spinal shape. *J. Applied Statist.* **26** 735–745.
- MARDIA, K. V. and WATKINS, A. J. (1989). On multimodality of the likelihood in the spatial linear model. *Biometrika* **76** 289–295.
- MARDIA, K. V. and ZEMROCH, P. J. (1978). *Tables of the F- and Related Distributions with Algorithms*. Academic Press, New York. [Russian translation (1984). Nauka, Moscow.]
- NEWRICK, P. G., AFFIE, E. and CORRALL, R. J. M. (1990). Relationship between longevity and life-line: a manual study of 100 patients. *J. Roy. Soc. Medicine* **83** 499–501.
- ORD, J. K. (1972). *Families of Frequency Distributions*. Griffin, London.
- PEARSON, E. S. and HARTLEY, H. O. (1972). *Biometrika Tables for Statisticians 2*. Cambridge Univ. Press.
- PITT, H. R. (1963). *Integration, Measure and Probability*. Oliver and Boyd, London.
- PLACKETT, R. L. (1965). A class of bivariate distributions. *J. Amer. Statist. Assoc.* **60** 516–522.
- RAO, C. R. (1952). *Advanced Statistical Methods in Biometric Research*. Wiley, New York.
- RIPLEY, B. (1981). *Statistical Inference for Spatial Processes*. Cambridge Univ. Press.
- SWITZER, P. (1983). Some spatial statistics for the interpretation of satellite data (with discussion). *Bulletin of the International Statistical Institute* **50** 962–971.
- WATSON, G. S. (1973). Review of K. Mardia's "Statistics of Directional Data." *Technometrics* **15** 935–936.
- WHEELER, S. and WATSON, G. S. (1964). A distribution-free two-sample test on a circle. *Biometrika* **51** 256–257.
- WISHART, J. (1928). The generalized product moment distribution in samples from a normal multivariate population. *Biometrika* **20A** 32–52.